Conference on Quantum Foundations

Ontological Problems 80 Years after EPR

V Jornadas de Fundamentos de Cuántica (VJFC)

Problemas Ontológicos a 80 Años de EPR

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The ontological status of the wave function in Bohm's theory

Pablo Acuña
Pontificia Universidad Católica de Chile

In 1952 David Bohm proposed a quantum theory (which had been independently formulated by de Broglie in 1927) that postulates a dualistic ontology: quantum particles whose trajectories are determined by a 'pilot wave'. This theory has important advantages over standard quantum mechanics in Hilbert space. The de Broglie-Bohm proposal is not troubled by any kind of measurement problem, and it provides a clear and visualizable account of many quantum peculiar phenomena, such as interference patterns in the trajectories of particles and entangled correlations. However, the ontological status and physical description of the pilot wave are rather troublesome. First, unlike its classical counterparts the quantum field associated to psi does not have a source. Second, the pilot wave does not respect the 'action reaction principle': although it affects the particles by guiding their trajectories, it is not affected back by the particles. Third, for an N-particle system, the pilot wave and its evolution are described in $3N$-configuration space rather than in physical 3-space.

Quantum mechanics with non-individuals

Jonas R Becker Arenhart
Federal University of Santa Catarina

Current debates about the metaphysical nature of quantum particles is dominated by the opposition between structuralist (Ontic Structural Realism) and non-structuralist approaches. Structuralist approaches, roughly speaking, advance the thesis that quantum particles have nothing to their nature beyond what is attributed to them by the structure they are part of; that is said to be in complete agreement with quantum mechanics and what it teaches about quantum particles. Non-structuralist approaches, on the other hand, are usually thought of as requiring that the entities must have an 'individual profile' or a 'principle of individuality', and that fact would conflict with some of the main features of quantum mechanics. We propose that a non-structuralist approach based on the notion of non-individuality is a viable option. Non-individuals have no individual-profile and as we shall argue, may overcome some of the main difficulties with structuralist ontologies.

A dimensional link between quantum and classical correlations

Guido Bellomo
Instituto de Física La Plata

Quantum correlations play an important role in our today's understanding of Quantum Mechanics, providing a way to assess the differences with its Classical counterpart. However, when one realizes that the very notions of quantum systems/subsystems and quantum states are not yet fully understood or agreed upon, from the ontological point of view, ambiguities arise: Correlations between what? How to correctly identify them? To answer these kinds of questions, the concepts of separability, locality, and causality seem to be crucial. We are going to discuss some of these issues from an algebraic and information-theoretic perspective, based on some previous works that attempt a generalization of the entanglement notion [1-3]. We will analyze the relative character of general correlations in quantum systems, and their relation to an interesting new link between quantum and classical correlations, first encountered by Li and Luo [4]. In particular, we will show some analytical and numerical results for low-dimensional systems [5-7].

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What an interpretation of quantum mechanics should be

Alejandro Cassini
CONICET - Universidad de Buenos Aires

I contend that quantum mechanics is an interpreted theory, and that there is a wide consensus on the physical meaning of its mathematical formalism. On the other hand, I argue that it is not clear what we should expect from a full interpretation of that theory, as opposed to the minimalist interpretation of the working scientist.

General factorizing fields and entanglement in finite spin systems

Marco Vinicio Sebastián Cerezo de la Roca
Instituto de Física La Plata and Universidad Nacional de La Plata

The ground state of strongly interacting spin systems immersed in a magnetic field can exhibit, under certain conditions, the remarkable phenomenon of factorization, i.e., of becoming a product of single spin states. Such exact factorization can occur at finite fields despite the strong couplings existing between the spins, albeit at very specific values of the field. In this work we determine the conditions for the existence of non-transverse factorizing magnetic fields in general spin arrays with anisotropic XYZ couplings of arbitrary range. We derive the equation of the factorizing fields determining uniform and Néel type separable ground states and we show that in the the vicinity of these fields the pairwise entanglement reaches full range. These results have let us to develop recipes for “separable ground state” engineering as these states can be useful for quantum information and quantum computation applications.

Quantum stochastic processes

Alberto Clemente de la Torre
Universidad Nacional de Mar del Plata

Several stochastic processes involving creation, annihilation and diffusion of virtual particles are presented whose mean field equations are the usual time evolution equations of quantum field theory.

Irreversible decoherence of dipole interacting nuclear spins coupled with a phonon bath

Federico Dominguez
Facultad de Matemática, Astronomía y Física - UNC

Quantum dynamics of dipole interacting spin ensembles in solids arouses great interest in various fields of modern physics, both fundamental and applied. Decoherence and irreversibility are essential pieces for the understanding of the complex dynamics which precedes equilibrium, and they are ultimately linked with basic open questions such as the emergence of thermodynamic equilibrium from the underlying microscopic unitary quantum dynamics and the measurement problem of quantum mechanics. Within this context, is the challenging problem of explaining the mechanism that enables spins in solids to attain a quasi-equilibrium state over an early time scale -in their transit to equilibrium- long before the process governing thermalization may

have acted. In this work we study the adiabatic decoherence of a system of dipole coupled spins interacting with a phonon bath. The system-environment coupling is introduced through the variations that the phonon field produces on the local dipolar energy, considered as the main contribution. The proposed model allows the estimation of decoherence rates in terms of parameters of the system. We contrast the predictions of this model with experimental results obtained using Nuclear Magnetic Resonance techniques.

Event ontology in quantum mechanics and the problem of strong emergence

Rodolfo Gambini
Universidad de la República

I analyze the applicability of event ontology in some quantum mechanical interpretations and show that it allows us to formulate in a more rigorous way the issue of emergence. I prove that the quantum theory implies that the lower levels are modified even up to the point where they lose part of their individuality when they are integrated into an entangled system in a higher level of the hierarchy. The emergent structure presents novel properties and downward causation.

Gaussian ensembles from an information geometric approach

Ignacio Sebastian Gomez
Insituto de Física de Rosario - CONICET and Facultad de Ciencias Exactas - UNLP

We present the gaussian emsembles of random matrix theory as a particular case of the information geometrodynamical approach to chaos (IGAC) applied to models of statistical manifolds. Moreover, with the aim of unify some characterizations, using IGAC we also propose a geometrodynamical version of the ergodic hierarchy which allows to place the gaussian ensembles within the more chaotic level, i.e. the Bernoulli level. This proposal justifies the validity of application of the gaussian ensembles in strongly chaotic quantum systems.

Logical and geometrical aspects of the violation of Bell inequalities

Federico Holik
Institu de Física La Plata - CONICET and Universita di Cagliari

The non-abelian character of the logic of quantum theory gives rise to a rich structure of correlations between different systems. Many years after, entanglement is a subject of immense attention, mainly because of its foundational significance. Quantum discord, has also been an important subject of study.

The study of the geometric and algebraic properties of the convex set of states responsible of the quantum correlations is of paramount importance. In order to characterize it, many mathematical strategies have been developed. These range from the application of algebraic tools to group theory, algebra, differential geometry, convex geometry, numerical simulations, etc. In this talk we give an overview of these topics and pose a discussion regarding the ontological problems related to the EPR problem and Bell inequalities. In particular, we discuss the relationship between the non-Kolmogorovian character of quantum probabilities and the violation of Bell inequalities.

Quantum mechanics and classical logic: the problems with the theory of identity of classical logic

Décio Krause
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Standard textbooks of quantum theory (both orthodox quantum mechanics and the quantum field theories) don't speak of logic ("quantum logic" is a different subject than an attempt to ground quantum theory in such a basis). The mathematical developments are done using informal mathematics, and consequently, informal classical logic. If pushed, the philosopher of physics (hardly the physicist, unfortunately) may speak of something like the ZFC set theory, which encompasses a classical logic of some sort (generally, ZFC is developed as a first-order system). But quantum theory (Bohm's theory will be left out of this discussion) presupposes that some quantum objects (whatever they are) may, in some cases, be absolutely indiscernible, say a group of bosons in the same quantum state. But ZFC (and informal mathematics) encompasses the classical theory of identity which, summing up, says that any two objects are necessarily different, although sometimes the differences cannot be made explicit (but it exists at least as something hidden by the mathematical formalism). That is, Leibniz Principle of the Identity of Indiscernibles is a theorem of such a logic. Hence we face a dilemma if we wish (as I wish - see Arenhart and Krause 2014) to sustain that quantum objects are better viewed (in some cases) as legitimate indiscernible objects (yes, to me they are 'objects' of some kind, entities to which we attribute properties and make discourses): either we continue to work within a theory like ZFC and add some mathematical trick for veiling the existent (by force of logic) individuality of the considered objects (Permutation Symmetry -PS- of any sort is no more than one of these tricks), or we need to pursue an adequate logic-mathematical basis in which quantum theory can be developed, and which enables us to consider indiscernible objects from the start. This theory does exist, and is called quasi-set theory (French and Krause 2006), and some advances in developing a quantum mechanics within its framework (Domenech et al. 2008, 2010) show that PSs may be dispensed with. Here we outline, for a general audience, the main philosophical motivations mentioned above but do not present all the logical details of our approach, which is still in course.

Time-energy uncertainty relation revisited

Pedro Walter Lamberti
Facultad de Matemática, Astronomía y Física - UNC and CONICET

Among the uncertainty relations, the time-energy is the most difficult to be interpreted. Are well known the Einstein-Bohr discussions concerning to the meaning of this uncertainty relation. In this talk we review the historical development of this relation and we present different interpretations of it.

Facing the interpretive challenges of quantum mechanics from an ontolgy of properties

Olimpia Lombardi
CONICET - Universidad de Buenos Aires

In previous papers we have proposed the modal-Hamiltonian interpretation of quantum mechanics, a new member of the "modal family", according to which the Hamiltonian of the system plays a determining role in the selection of the preferred context of definite-valued observables. The interpretation was applied to several well-known physical situations (free particle with spin, harmonic oscillator, free hydrogen atom, Zeeman effect, fine structure, the Born-Oppenheimer approximation), leading to results consistent with empirical evidence. Moreover, it proved to be able to supply an account of the measurement problem, both in its ideal and its non-ideal versions, and to supply a criterion to distinguish between reliable and non-reliable non-ideal measurements. Furthermore, it was expressed under a group-invariant form, its links with quantum decoherence were studied, and its extrapolation to quantum field theory was considered.

In the present talk I will not focus on these technical interpretive matters, but I will consider the ontological picture supplied by the modal-Hamiltonian interpretation: a modal ontology of of type- properties, whose modal nature consists in the fact that they only determine the possible case-properties of a quantum system, but not its actual case-properties. From this perspective, a quantum system is conceived as a bundle of type-properties. The purpose of this work is to argue that this modal ontology of properties offers a unified solution to the three main ontological problems of quantum mechanics: contextuality, indistinguishability and non-separability.

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Some remarks about (symmetric?) time in quantum mechanics

Cristian López
Universidad de Buenos Aires and CONICET

The aim of this presentation is to consider the problem of the arrow of time in quantum mechanics. We will begin by recalling the different results obtained from applying the Wigner operator $T*$ and the Racah operator T to the Schrödinger equation: quantum mechanics is both $T*$-invariant theory and T-non-invariant. To tackle this situation, we will consider two alternatives: (i) to accept that QM is not time-reversal invariant, in contradiction to the commonly accepted assumption; (ii) to agree with the common opinion that QM is time-reversal invariant, but in contradiction to idea that the time-reversal operator must be defined independently of the theory. We will discuss this alternatives and we will wonder to what extent is it possible to define an "objective" time reversal operator in quantum mechanics.

The measurement process in the generalized contexts formalism for quantum histories

Marcelo Losada
Instituto de Física de Rosario

The quantum histories approach was developed in order to give an interpretation of quantum mechanics in which there is no collapse postulate and the measurement is considered as a quantum interaction between the measured system and the measurement instrument. Our formalism of Generalized Contexts is one of these formalisms of quantum histories, which allows to define expressions with properties at different times and enables to organize them in a valid quantum history.

In this talk we applied this formalism to two consecutive non-ideal measurements on the same system. The measured system S and both measurement instruments A and B form a composed quantum system with a valid description, involving the possible pointer values of the instruments immediately after each of the two successive measurements. We proved that the possible values of the pointer variables, corresponding to two consecutive measurements on a system S are always compatible properties. Therefore, it is possible to use the formalism of Generalized Contexts to compute the probability for each result of the second measurement with instrument B, conditional to a given previous result of the firs measurement with instrument A. We proved that the value of this conditional probability is the same that would be obtained performing only a measurement with instrument B on the system S in an effective state. This effective state depends on the result of the first measurement. Only in the case of an ideal measurement the effective state coincides with the state obtained applying the state collapse postulate.

Quantum decoherence in the understanding of optical isomerism

Juan Camilo Martinez and Sebastian Fortin
CONICET - Universidad de Buenos Aires

In the present paper we address the problem of optical isomerism embodied in the so-called Hund's paradox, which points to the difficulty to account for chirality by means of quantum mechanics. In particular, we explain the answer to the problem proposed by the theory of decoherence. The purpose to this article is to challenge this answer on the basis of a conceptual analysis of the phenomenon of decoherence, that reveals the limitations of the theory of decoherence to solve the difficulties posed by optical isomerism and, in general, by quantum measurement.

Geometric probability theory and Jaynes's methodology

César Massri
Departamento de Matemática - UBA and CONICET

The notion of geometric probability was characterized by Gian Carlo Rota as the study of invariant measures. This idea has lead to interesting mathematical problems, which have defined a rich field of study. In this talk, we give an introduction to Rota's theory and then, we apply it to generalized probabilistic physical theories. Also, we reformulate Jaynes's MaxEnt approach (maximization of entropy) in geometric probability terms allowing for the inclusion of group actions representing physical symmetries. In this talk, we give special attention to the mathematical an geometrical structure.

From EPR to Bell to today

Tim Maudlin
New York University

Albert Einstein's objections to quantum theory have been systematically misrepresented in both popular accounts and by prominent physicists. Einstein is portrayed as unable to accept indeterminism. But his main objection to the Copenhagen approach was not to the indeterminism but rather to an implicit non-locality, "spooky action-at-a-distance", that was implied by the Copenhagen interpretation even when not required by the phenomena. The point of the EPR argument was to show this, and to conclude that a deterministic theory was needed to restore locality. John Bell understood this, and pushed further to investigate whether any local theory could recover all of the predictions of quantum theory, not just the EPR predictions. But Bell's reliance on the EPR argument coupled with misunderstanding of EPR has resulted in widespread misunderstanding of what Bell proved. I will review EPR, Bell's theorem, and the present state of widespread misunderstanding.

Ψ-A metaphysical quandary

Vishnya Maudlin
New York University

The question of ontology of the physical world used to be a prerogative of physicists. Physicists would tell us what exist in the physical world according to their theories. For example, Newton was very explicit about the structure of space and time that he postulated. With the advancement of quantum mechanics and mathematical representation as the main language in which theories are written, the ontological commitments of theories became unclear. The old metaphysical question of what exists even according to the theory became more difficult to answer. Every quantum mechanical theory has the wave function as an integral part of its mathematical formalism. The wave function is a mathematical object described on configuration space that is a multi-dimensional space. The multi-dimensionality of the space on which the wave function lives has led to the discussion of its ontological status as a representation of the quantum state of a system. According to Ψ-epistemic view, the quantum state represents the state of our knowledge and not the state of the world, while according to Ψ-ontic view, the quantum state represents underlying physical state. There are two questions I will consider in my talk. One question arises from a recent paper by Pusey, Barrett, and Rudolph that purports to show that a Ψ-epistemic theory cannot reproduce predictions of quantum mechanics and, therefore, the only option is to regard the quantum state as real. The other question is what we are committing ourselves to if we take the quantum state to be real. In particular, does a commitment to the reality of the quantum state entail a commitment to the reality of a high-dimensional physical space corresponding to the mathematical space used in the formalism? How does our familiar understanding of space-time fit into this picture?

Hypergeometric connotations of quantum equations

Angel Plastino
CONICET - Universidad Nacional de La Plata

We show that the Schroedinger and Klein-Gordon equations can both be derived from an Hypergeometric differential equation. The same applies to non linear generalizations of these equations.

An ontological model for the description of classical systems with incompatible experiments

Manuel Sáenz and Pablo Terren Alonso
Facultad de Ciencias Exactas y Naturales - UBA and CONICET

In the last decade, there has been an extensive debate on the ontological character of quantum states. On one side, in the epistemic view, quantum states represent a rational agent's personal probability assignments. In contrast, the realist view of quantum states interprets them as an element of physical reality. It has been pointed out that these discussions could contribute to issues related to quantum information and computation. Recent theorems have shown that the quantum state must be ontic (a state of reality) in a broad class of ontological models. These results indicate that the epistemic nature of quantum states constitutes (as a physical assumption) a strong constraint. In this talk, we will present a procedure for the construction of logical structures that could be used to study the states of classical systems described by means of a set of incompatible experiments. The resulting scheme (which can be interpreted as a type of contextual ontological model) shows similarities to the quantum case. We will conclude with a brief discussion on the relationship of this construction with the ontological model approach and some of the known no-go theorems.

Deterministic explanations of non-local correlations have to be uncomputable

Gabriel Senno
Facultad de Ciencias Exactas y Naturales - Universidad de Buenos Aires

Quantum mechanics postulates random outputs. However, a model making the same output predictions but in a deterministic manner would be, in principle, experimentally indistinguishable from quantum theory. In this work we consider such models in the context of non-locality on a device independent scenario. That is, we study non-local boxes that produce their outputs deterministically. For these boxes to be non-local at least one of the boxes' output has to depend on the other party's input via some kind of hidden signaling. We prove that, if the deterministic mechanism is also algorithmic, there is a protocol which, with the sole knowledge of any bound on the time complexity of such algorithm, extracts that hidden signaling and uses it for the communication of information.

Reaching into the past: or how to slay Wheeler's smoky dragon in delayed-choice experiments

Pieter Thyssen and Sylvia Wenmackers
KU Leuven, Institute of Philosophy

Ingrained in our scientific mindset is the arrow of causality - the idea that causation is time–asymmetric such that causes precede their effects temporally. In recent years however, due in large part to the puzzles of quantum mechanics, scientists as renowned as John Wheeler, George Ellis and Yakir Aharonov have played with the idea that causality might be a two–headed arrow, and that choices made now might influence what has already happened.

The aim of this talk is to gauge the potential of such retrocausal in influences in quantum mechanics and to tease out the profound implications it would have for the nature of reality. My talk will be built around the ideas of two central figures in the debate: the American physicist, John Archibald Wheeler (1911-2008), and the Israeli physicist, Lev Vaidman (°1955).

It is often said that Wheeler was among the first to invoke backward causation (or retrocausation) in quantum mechanics in order to explain his now famous delayed-choice experiments. In one version of this experiment, the choice of whether or not to insert a second beam splitter in a Mach–Zehnder interferometer (MZI) is delayed until after the photon has passed the first beam splitter. Since the absence/presence of the second beam splitter determines whether the photon will take a single path/both paths, it looks as if our present choice can affect the past in a retrocausal way.

Curiously enough, Wheeler's own interpretation of this experiment was at best ambivalent - leaving the reader in doubt as to whether he entertained the idea of retrocausation or not.

The first part of my talk, therefore, will be largely historical. After taking a closer look at the Wheeler corpus, I will disentangle three (mutually exclusive) views one can attribute to Wheeler: 1. the present can change/aect an already existing past, 2. the present brings about/creates the past, 3. the past is only theory.

With regard to the third view, Wheeler likened the photon in a MZI to a "great smoky dragon". In this typical Wheeler metaphor, the points of entry and reception of the photon in the MZI are indicated by the tail and mouth of the dragon, "but in between all is cloud". In other words, asking which path the photon took is completely nonsensical.

I will argue that whereas Wheeler clearly rejected the first view, he remained annoyingly ambivalent when it came to favouring either the second (ontic) or the third (epistemic) view. Interestingly, this confusion has persisted till the present day. I will show that whereas scientists such as Davies, Ellis and even Hawking keep defending the second view, most physicists prefer the third view.

If time permits, I will briefly turn to the more recent work by Vaidman in the second part of my talk, and contrast his views with Wheeler's. Using a nested MZI, Vaidman attempted to analyse the past of a photon according to the weak trace it leaves behind. I will evaluate to what extent such weak measurements can indeed enable us to slay Wheeler's smoky dragon in order to ascertain which path the photon really took.

Whereas Vaidman's results seem to be in conflict with most interpretations of QM, the (time-symmetric) two-state vector formalism (TSVF) on the other hand, elegantly accommodates the results | thereby indicating that the past of a particle is dependent on both the forward- and backward-evolving quantum states. While this brings retrocausation back in the spotlights, it remains an open question whether an explanation can be provided that does not require introducing retrocausality.