Editorial: Towards a Local Realist View of the Quantum Phenomenon

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Editorial on the Research Topic

Towards a Local Realist View of the Quantum Phenomenon

Quantum mechanics (QM) stands apart from other physical theories inasmuch as its elegant and powerful mathematical formalism conceals the lack of a unique, complete, and coherent conceptual frame in which to accommodate the physical elements that should be put into correspondence with the mathematical objects. Excessive mathematization, blurred physics, and the abandonment of principles on which the remainder of physics rests—such as realism, determinism, locality, objectivity or descriptiveness—have been a discomforting signature in the legacy of QM as we know it.

An aim of this Research Topic was to promote discussions of the physics of QM as seen from different perspectives. Authors were invited to take a closer look beyond the formal apparatus, and point towards new paths for a more physical and realist reframing of QM. The 15 articles included in this issue represent different endeavors to identify underlying physical laws and causal connections, propose a possible "subquantum" theoretical description, revise the rules of correspondence between theory and observation, or offer logical arguments viz. concrete models that question the impossibility theorems.

The introductory statement by Gerard 't Hooft (Hooft) carries the torch for many an article in this issue: "Without wasting time and effort on philosophical justifications and implications, we write down the conditions for the Hamiltonian of a quantum system for rendering it mathematically equivalent to a deterministic system." The natural flow and simplicity of 't Hooft's article are signatures of great mastership that raises the question why we have considered in the past all these philosophical justifications. The answer is, of course, that they trace their origin to the writings of Heisenberg, Bohr, and Einstein. There exists in addition a massive literature on Bell-type inequalities that claims to go beyond philosophy. Bell's theorem has been circumvented by extreme interpretations of experiments with atomic and subatomic entities. One extreme is the increasingly fashionable inference of superluminal "influences" (not information transfer), and the other extreme is the super-determinism as discussed in more palatable forms in the article of Hossenfelder and Palmer (Hossenfelder and Palmer).

Bell's theorem has come to represent a major stumbling block in the search of local realist and deterministic descriptions of our world. Several contributions to this issue, however, demonstrate that it does not constitute the unmovable obstacle that it was thought to be, because it is not only difficult to relate to any actual experiments but also contains questionable physical assumptions. Oaknin (Oaknin) demonstrates that the derivation of Bell-type inequalities suffers from deep physical problems related to the gauging of Bell's variables, which requires an absolute frame of

reference. He shows further that the constraint that Bell-type inequalities supposedly force on the statistics of experimental outcomes may be removed by considering the involvement of gauge symmetries and geometric phases. De Raedt et al. (De Raedt et al.) construct a subquantum model of the Einstein–Podolsky–Rosen–Bohm experiment. Their work uses a digital computer and a discrete-event simulation as a metaphor for idealized, realizable laboratory experiments. All of their variables, including those representing macroscopic events, have definite values and change in time according to an Einstein-local, causal process. Willsch et al. (Willsch et al.) demonstrate further that their Einstein-local simulation models in which particles follow well-defined trajectories, reproduce the results of quantum walk experiments.

A recurrent idea in the present volume is that realism need not be abandoned if one gets rid of concepts such as non-disturbing measurements and non-contextuality. In particular, the evidence against local non-contextual hidden variables offered by many spin–polarization correlation experiments may coexist with a local, causal, realist description of Nature. The possibility of describing physical phenomena with these cherished principles has not been ruled out by some clicks on detectors. Kupczynski (Kupczynski) presents an overview of arguments in support of the idea that the violation of Bell-type inequalities does not necessarily imply the existence of spooky actions at a distance, nor a compulsory renounce to an objective physical reality, provided contextual setting-dependent parameters are included in the description. Such violation simply shows us that "entangled photon pairs cannot be described as pairs of socks nor as pairs of fair dice." Jung (Jung) demonstrates that the strong polarization correlation of entangled photon pairs produced in parametric down conversion can be calculated from wave-like considerations, by assuming a fixed relative phase of the two associated wave packets at the source. As a consequence, the distance between detectors in the Bell-inequality test of local realism becomes irrelevant, and the consideration of faster-than-light communication has no sense at all.

Also Sulis (Sulis) insists in a contextual reality, and proposes an ontological model that incorporates a minimalistic definition of generated reality, possesses a non-Kolmogorov probability structure, and is consistent with nonrelativistic QM. In this scenario, nonrelativistic QM appears as an effective, approximate theory, and the Hilbert-space formalism—extraordinarily useful for the practical purpose of performing calculations—fails in providing an ontological model of QM, ultimately leading to many of its conundrums. The problem lies not with reality but rather with the mathematical tools employed to represent it. All of these facts reaffirm Gerard 't Hooft's enunciation against wasting time and efforts on perceived obstacles that lie outside the direct mathematical physics.

A further specific local realistic interpretation of the entangled photon pairs is offered by Santos (Santos), who studies the generation of polarization-entangled photon pairs produced in parametric down conversion using the Weyl–Wigner formalism in the Heisenberg picture, a more formal approach of quantum optics than the one used by the author and coworkers in previous articles. The picture that emerges resembles classical optics by taking into account the zero-point radiation field entering the nonlinear crystal as a real stochastic field, and entanglement corresponds to a correlation of fluctuations between a signal and a vacuum field in distant places. A detailed discussion is made about the detection process and the relationship of this approach to local realism. Further, in a study by Casado et al. (Casado et al.) the Wigner representation in the Heisenberg picture is used for the study of the quintessential experiment on quantum teleportation, the Innsbruck experiment. The visible presence of the zero-point field is stressed, and new physical insights are given that lead to a deeper knowledge of this experiment. Concretely, entanglement and the collapse postulate are replaced by the consideration of the quadruple correlation properties of the field corresponding to the propagation of two couples of independent photon pairs. The role of the vacuum inputs in Bell-state analysis is investigated, with its presence reinforcing the idea of the zero-point amplitudes as "hidden variables."

Consideration of the effects of the zero-point field on the dynamics takes us to the realm of stochastic electrodynamics (SED), which has been developed to provide a concrete local realistic explanation of the quantum behavior of matter. Cole (Cole) uses a new technique based on SED, to successfully calculate probability–density and n-point correlation functions, both for the complete Planckian field including the zero-point component, and for an electric dipole oscillator embedded in it. The H atom, however, turns out to be far more difficult to deal with. Cole's elaborate but transparent method makes an interesting contrast to Feynman's path-integral approach—where also the H atom appeared to be intractable for more than 3 decades. Considering the importance of finding a proper treatment of SED to describe the H atom, Nieuwenhuizen (Nieuwenhuizen) makes a renewed attempt to avoid self-ionization by studying the atom's ground state perturbed by the zero-point field and using several renormalization schemes that suppress high-frequency tails, which however do not lead to a satisfactory solution. While in the approaches of Cole and Nieuwenhuizen the zero-point field merely perturbs the classical motion, de la Peña et al. (Peña et al.) argue that its influence is far more profound and leads to a nonclassical dynamics. The contact made between SED and stochastic quantum mechanics serves to demonstrate that Newton's second law is modified in an essential way by stochasticity, which is at the core of the transition to the quantum dynamics. The interplay of diffusion and radiation reaction allows the system to converge towards a balance regime, thus offering an explanation for atomic stability.

The wave element, from the outset present in SED, provides a natural bridge to the work by Durey and Bush (Durey and Bush), who ably harness insights gained from the hydrodynamic walking-droplet system to further develop their de Broglie-inspired model of quantum dynamics, and thus lay the foundations for deeper study of what they term hydrodynamic quantum field theory. A complex and detailed analysis, both theoretical and numerical, serves to show that the pilot wave is a combination of short, Compton-scale waves that propagate away from the moving particle, and a de Broglie-scale carrier wave—just as envisaged by de Broglie and reaffirmed in SED. Finally, that the wave–particle duality can be discussed in the light of a causal and objectively realist model of the electron is demonstrated by Avner and Boillot (Avner and Boillot). Their

relativistic electrodynamical model of the subatomic particle at rest involves charged sub-particles following definite trajectories, and stands in sharp contrast with the Heisenberg (widespread) belief that only the abstract (mathematical) description of particles exists. The authors thus direct their attention to explore the gears of one of the most emblematic quantum particles, within an approach that supports the principles of determinism, causality, and objective reality.

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