Foundations of Quantum Mechanics

C. Garola,[1 2] M. Persano[1 2] and S. Sozzo[1 2]

[1]Dipartimento di Fisica, Università del Salento, Italy

[2]Istituto Nazionale di Fisica Nucleare, Sez. di Lecce, Italy

The subgroup concerned with the *Foundations of Quantum Mechanics* has worked on four different but interconnected research topics.

(i) A refined and improved version has been devised of the *extended semantic realism* (*ESR*) *model* proposed several years ago by the Lecce group [1,2]. The ESR model supplies now a new theoretical perspective which avoids the objectification problem of the quantum measurement theory by embodying the basic mathematical formalism of standard (Hilbert space) quantum mechanics (QM) into a broader formalism which admits a noncontextual (hence local) interpretation. This result is obtained by reinterpreting quantum probabilities as conditional on detection instead of absolute, which allows one to overcome known "no-go theorems". As a consequence, the ESR model yields some predictions that differ from those of QM, hence it is, in principle, falsifiable.

Furthermore a mathematical representation has been elaborated which associates every generalized observable introduced by the ESR model with a *family of positive operator valued* (*POV*) *measures* parametrized by the pure states of the physical system that is considered [3]–[9]. This representation allows one to evaluate absolute and conditional probabilities both in the case of pure states and in the case of proper mixtures, and implies a nonstandard representation of proper mixtures in terms of *families of density operators* parametrized by the physical properties characterizing the system. The new representation avoids some deep interpretative problems of the standard representation and implies a nontrivial generalization of the Lüders postulate, which can be partially justified in terms of a *nonlinear* evolution scheme. Moreover, these results imply that Bell's inequalities must be replaced by *modified Bell's inequalities* in the ESR model, and that the standard quantum expectation values, when reinterpreted as conditional expectation values, do not violate the latter inequalities. Hence the long–standing conflict between "local realism" and QM is settled in the ESR model.

(ii) Coming to logical and epistemological issues, the known Einstein–Bohr debate about the completeness of QM has been discussed to single out the notions of truth implicitly accepted by the opponents [10]. It has been shown that Einstein and Bohr adopted different notions, and that each of them was right with respect to his own notion. Einstein's view, however, is usually rejected by physicists because it clashes with some "no–go" theorems that were proven afterwards. It has then been shown that these theorems rest on an implicit epistemological assumption that can be criticized, which brings back to Einstein's perspective as a consistent alternative that opens the way to interesting completions and reinterpretations of QM.

Furthermore, an analysis of the various notions of realism occurring in physical theories has been performed which shows that, at variance with a widespread belief, all existing interpretations of QM (except for the statistical interpretation) presuppose a minimal form of realism which consists in assuming that QM deals with individual objects and their properties [11,12]. It has been demonstrated that the standard arguments supporting the contextuality and the nonlocality of QM are a significant clue to the implicit adoption of stronger and compelling forms of realism (*realism of theoretical entities* and *realism of theories*), notwithstanding the asserted "antimetaphysical" character of standard QM. If these kinds of realism are substituted by the simpler and more intuitive *semantic realism* adopted in the ESR model several fundamental problems of standard QM are avoided.

Finally a procedure has been worked out which allows one to recover classical and nonclassical logical structures as *concrete logics* associated with physical theories expressed by means of classical languages [13]. By applying this procedure one recovers a classical logic as the concrete logic associated with classical mechanics and standard quantum logic as the concrete logic associated with QM. These results show that some nonstandard logics can be obtained as mathematical structures formalizing the properties of different notions of verifiability in different physical theories. More generally, they strongly support the idea that many nonclassical logics can coexist without conflicting with classical logic (*global pluralism*), for they formalize metalinguistic notions that do not coincide with the notion of truth.

(iii) A joint research with the subgroup concerned with *Open Quantum Dynamics* on the *subentity problem* in QM has been completed [14]. It has been proven that, if one adopts the general formulation of QM on quaternionic Hilbert spaces, proper and improper mixtures can be represented by different kinds of density operators. This representation is compatible with the different evolutions of the two kinds of mixtures in complex QM, hence it allows one to distinguish proper from improper mixtures not only from an interpretative but also from a mathematical point of view, which does not occur in standard QM.

(iv) A collaboration has been started with the research group on the foundations of QM in Brussels, mainly concerning the identification of quantum structures in nonphysical fields such as cognitive sciences, economics, biology, etc. A contextual quantum–based formalism for ecological systems together with an extension of the Lotka–Volterra equations for contextual systems have been elaborated [15]. The analytic solutions of these generalized equations allow one to propose an alternative explanation of some paradoxes that occur whenever classical approaches based on the Lotka–Volterra equations are applied to population ecology. A novel approach has also been proposed to model the data collected in some experiments carried out in psychology to estimate typicalities of exemplars of concepts and their combinations [16]. It has been proven that the new perspective resolves some fundamental difficulties, as the *guppy effect*, arising in classical approaches and on the world–wide web whenever data on concepts and their combinations are collected by using search engines. A quantum–based model has been propounded which agrees with empirical data also in the latter case.

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