Truth and Completeness in Quantum Mechanics: A Semantic Viewpoint

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Abstract

The Einstein, Podolski and Rosen (EPR) argument aiming to prove the incompleteness of quantum mechanics (QM) was opposed by most EPR’s contemporary physicists and is not accepted within the standard interpretation of QM, which maintains that QM is a complete theory. An analysis of the semantic implications of the opponent positions shows that they imply different notions of truth. The introduction of a nonclassical notion of truth within the standard interpretation is usually justified by referring to known theorems that should prove that QM is a contextual and nonlocal theory. However, these theorems are based on a doubtful implicit epistemological assumption. If one renounces it, one can provide an alternative interpretation of QM that it realistic in a semantic sense. Within this interpretation the EPR viewpoint is recovered and QM is considered a (semantically) incomplete, noncontextual and local theory. Furthermore, the new interpretation provides several suggestions for constructing a more general theory embedding QM and for connecting QM with classical physics and relativity.

Key words: quantum mechanics, completeness, quantum truth, standard interpretation, SR interpretation.

1 Introduction

The famous paper by Einstein, Podolski and Rosen (EPR) aiming to prove the incompleteness of quantum mechanics (Einstein et al., 1935) opened a debate that is still alive among scholars concerned with the foundations and the philosophy of QM. It is well known that the EPR position was not accepted by the majority of contemporary physicists, and that the viewpoint of EPR’s opponents (above all, Bohr’s) became the official doctrine of quantum physicists (briefly, even if imprecisely, Copenhagen, or standard, interpretation).

Basing on several papers by ourselves on topics connected with the EPR issue, we want to show in this article that a careful analysis of the semantic implications of the two positions greatly helps to understand the terms of the
debate and provides a new perspective for solving old quantum problems and avoiding known quantum paradoxes. To this end, we provide a brief summary of the EPR’s argument in Sec. 2, and resume their opponents’ arguments in Sec. 3. Then we argue in Sec. 4 that EPR’s viewpoint is compatible with the adoption of a classical (Tarskian) conception of truth as correspondence for a suitable fragment of the observative language of QM, while the standard interpretation adopts a non-Tarskian verificationist conception of truth for the same fragment. The choice of the standard interpretation is commented on in Sec. 5, where we remind that it is usually supported by some famous theorems that are maintained to prove that QM is necessarily a contextual and nonlocal theory. In the same section we show, however, that these theorems are based on an implicit epistemological assumption which contradicts the claimed anti-metaphysical character of QM. Thus, if one renounces this assumption, the standard interpretation does not appear any more as logically necessary, and one can envisage a new interpretation of QM that adopts the classical conception of truth mentioned above, so that, according to it, QM would turn out to be a noncontextual, local and incomplete theory, consistently with the EPR philosophical position. Finally, we remind in Sec. 6 that an interpretation of this kind has been actually constructed by ourselves (semantic realism, or SR, interpretation) and observe that this interpretation provides a number of hints for constructing a more general theory embedding QM and for connecting QM with classical physics (CM) and relativity. In particular, the SR interpretation suggests that the difficulties encountered by physicists when trying to interpret CM as a limit of QM, or to join consistently QM and relativity, could depend on the adoption of different concepts of truth within these physical theories (quantum truth, which produces contextuality and nonlocality, within the standard interpretation of QM; classical truth, which produces noncontextuality and locality, within CM and relativity). This incommensurability of theories would then be avoided if the SR interpretation of QM is accepted.

2 The EPR incompleteness argument

Let us schematize briefly the essentials of the EPR argument by using an updated terminology and following the scheme provided by Jammer in his fundamental book on the philosophy of QM (Jammer, 1974).

The EPR paper can be divided into four parts, as follows.

Part 1. The following conditions are stated.

Condition of completeness: “...every element of the physical reality must have a counterpart in the physical theory”.

Condition of reality: “If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity”.

Part 2. There are pairs of (noncompatible) observables whose values cannot both be known with arbitrary precision in QM (the position and the momentum
of a particle are observables of this kind). Hence, two alternatives occur.

(i) The values of the two observables are not simultaneously real.

(ii) QM is an incomplete theory.

Part 3. By considering a “combined” physical system consisting of two physical systems (actually, particles), say I and II, it is possible to prepare the combined system in a state S in which a measurement of the position of system I would allow one to predict with certainty, by using the laws of QM, the value of the position of system II, while a measurement of the momentum of system I would allow one to predict, again by using the laws of QM, the value of the momentum of system II. Furthermore, “since at the time of measurement the two systems no longer interact, no real change can take place in the second system in consequence of anything that may be done in the first system”. Hence, both the position and the momentum of system II correspond to elements of physical reality whenever the combined system is in the state S.

Part 4. The conclusion in Part 3 shows that the alternative (i) in Part 2 must be rejected. Hence, QM is an incomplete theory.

It is interesting to note that EPR’s argument is based on counterfactual reasonings, since the measurements of position and momentum on system I cannot be carried out simultaneously. The authors are well aware of this, for they wrote at the end of the paper:

“... one would not arrive at our conclusion if one insisted that two or more physical quantities can be regarded as simultaneous elements of reality only when they can be simultaneously measured or predicted. On this point of view, since either one or the other, but not both simultaneously, of the quantities P and Q can be predicted, they are not simultaneously real. This makes the reality of P and Q depend upon the process of measurement carried out on the first system, which does not disturb the second system in any way. No reasonable definition of reality could be expected to permit this.”

Thus, EPR based the defence of their conclusion on a sharp distinction between reality and empirical knowledge of reality. This distinction anticipates on the ontological ground the distinction between truth and epistemic accessibility of truth that will be discussed in Sec. 5.

3 The objections to the EPR argument

The reactions to the incompleteness argument summarized in Sec. 1 were immediate and generally critical (we refer again to Jammer’s book quoted in Sec. 2 for a detailed report on this issue). In particular, Bohr’s rejection of EPR’s conclusions (Bohr, 1935a, 1935b) was mainly based on his ‘relational conception of quantum states’. According to this conception, particles and experimental arrangements form an inseparable unit, so that no independent element of reality can be attributed to system II (hence EPR’s criterion of reality is refuted). The two measurements considered in the EPR argument are essentially different,
and the results obtained in them cannot be attributed to system II, separating this system from the two different “wholeness” to which it belongs in the two cases. Therefore, QM is a complete theory in the sense that there is nothing in the world besides what QM allows us to describe.

Bohr’s position resumed above is not completely accepted in the current manuals (see, e.g., Messiah, 1961; Cohen-Tannoudij et al., 1973; Greiner, 1989) reporting the standard interpretation of QM, where a position closer to Heisenberg’s (Heisenberg, 1961) is adopted. Indeed, whenever one considers a physical system made up by two subsystems, one usually accepts considering the properties of one of the component subsystems. Yet, for every state $S$ of the whole system one distinguishes between properties that are certainly possessed by the subsystem (i.e., properties that are real, or actual, in $S$) and properties that may be possessed or not (i.e., properties that are potential in $S$). In the physical situation described by EPR some properties of system II (to be precise, the property of having a sharp position and the property of having a sharp momentum), that are not actual in the state $S$, are actualized by the measuring processes, which also change the state. Yet, the property actualized in a position measurement is different from the property actualized in a momentum measurement, and the two properties do not refer to the same final state nor can be attributed to system II simultaneously. Thus, again, QM must be considered a complete theory in the sense expounded above.

The foregoing criticisms share a common feature. Both, indeed, consider QM as a contextual (in the sense that the measurement context cannot be separated by the physical system that is inquired) and nonlocal (in the sense that contextuality holds also at a distance) theory. Of course, nonlocality implies contextuality and contradicts EPR’s locality assumption that a measurement on system I cannot induce real changes on system II if the two systems no longer interact (Sec. 2).

Though nonlocality be fascinating because of the olistic perspective that it introduces in physics, its consequences are upsetting. Let us consider indeed its most immediate implications.

At a physical level it emerges an action at a distance that is completely different from the physical interactions described by the formalism of classical and quantum mechanics.

At an ontological level, some potential (real) properties of a physical system become real (potential) because of choices of an observer who can be as far away as desired from the physical system that is considered (though the observer cannot decide at will the final results of his measurements).

At a semantic level, there are statements that attribute physical properties to the system but have no truth value (hence no meaning) until some new knowledge about the system is attained by a far away observer.

Notwithstanding the problems pointed out above, nonlocality is accepted by most physicists as an intrinsic and unavoidable feature of QM. We will try to explain in Sec. 5 why an interpretation of QM has been adopted that is highly problematical, and to discuss whether there are alternatives to it. To this end, however, an intermediate step is needed.
4 Truth and semantic completeness in QM

The two different viewpoints about the completeness of QM discussed in Secs. 2 and 3 can be better understood in our opinion if one momentarily leaves apart any philosophical commitment and concentrates on a semantic investigation about the language of QM, pointing out in particular the truth criteria underlying it according to the two perspectives and the consequences about completeness (now meant in a purely semantic sense) that follow from these truth criteria. An investigation of this kind has been done by ourselves in some recent papers (Garola and Sozzo, 2004; Garola, 2005) and we cannot report it here in details. The essentials of our arguments can, however, be resumed as follows.

First of all, we must remind some features of the general epistemological perspective, or received viewpoint (Braithwaite, 1953; Hempel, 1965) that we adopt in this paper. According to this perspective, any physical theory $T$ is stated by means of a general language that contains, in particular, a theoretical language (which constitutes the formal apparatus of $T$ and contains terms denoting theoretical entities) and an observational language. The former is linked to the latter by means of correspondence rules, which provide a partial and indirect interpretation of it. The latter is interpreted by means of assignment rules, which make some symbols of the observational language correspond to macroscopic entities, as preparing or registering devices, outcomes of measurements, and so on.

Basing on the above scheme, let us observe now that, via assignment rules, any interpretation of $T$ adopts, often implicitly, a theory of truth, which defines truth values for some (not necessarily all) statements of the observational language. Whenever an interpretation is given, we call $T$ semantically objective with respect to a fragment $L$ of the observational language if and only if the theory of truth adopted in it defines truth values for all elementary statements of $L$. Furthermore, we call $T$ semantically complete with respect to $L$ if and only if, in any given physical situation, it allows to predict the truth values of all statements of $L$ that have a truth value according to the truth theory that has been adopted.

Let us come to EPR. These authors adopted in their paper an ontological form of realism (local realism, see Secs. 2 and 3) which is compatible with a classical theory of truth as correspondence, as explicated rigorously by Tarski (Tarski, 1956, 1944), for the observational language of QM. To be precise, let us consider an elementary statement $E(x)$ that attributes a physical property $E$ to a sample $x$ of the physical system in a given state $S$ (briefly called physical object in the following). This statement belongs to the standard observational language of QM, and the set of all statements of this kind constitutes a fragment of the observational language. Let us denote by $E$ the set of all properties that the physical object $x$ can possess, and let us denote the aforesaid fragment by $E(x)$, so that, obviously, $E(x)=\{E(x) \mid E \in E\}$. Then EPR’s local realism is compatible with the adoption of a classical (Tarskian) theory of truth for $E(x)$ (hence for a predicate calculus with standard connectives which has $E(x)$ as set of elementary formulas; we do not insist on this issue for the sake of brevity).
According to this theory all statements of \( \mathcal{E}(x) \) have simultaneous truth values (\textit{true/false}), hence QM is semantically objective with respect to \( \mathcal{E}(x) \). Yet, since the truth values of all statements of \( \mathcal{E}(x) \) cannot be simultaneously predicted by QM, QM is not semantically complete with respect to \( \mathcal{E}(x) \) \(^3\).

It is now important to remind that, according to the classical (Tarskian) theory of truth, truth values are defined by means of a set-theoretical model, so that their definition is independent of the existence of procedures which may lead to know them. Briefly, \textit{truth} and \textit{epistemic accessibility of truth} are different concepts. Thus, it can occur that the truth value of a statement \( E(x) \) is defined but cannot be known in a given physical situation.

Let us come to the standard interpretation of QM. This implies that a quantum concept of truth exists which is basically different from the classical concept. Indeed, the standard interpretation adopts a verificationist position which abrogates the distinction between truth and epistemic accessibility of truth. To be precise, it assumes that a statement of the form \( E(x) \) has a truth value if and only if it is possible to provide an empirical proof of it, thus unifying definition of truth and empirical accessibility of truth. The concept of empirical proof implied by this definition, however, is not trivial. Indeed, according to QM, every measurement on a physical object \( x \) generally modifies the state of \( x \), so that the obtained result refers to the final state and cannot be taken as indicative of the truth value of \( E(x) \). Taking into account this basic feature, and the canonical discussions usually carried out in order to provide an experimental basis to the indeterminacy relations (Jammer, 1974; Messiah, 1961; Cohen-Tannoudij et al., 1973; Greiner, 1989) one concludes that the following criterion of truth is implicitly adopted within the standard interpretation of QM.

**EV (empirical verificationism)** \(^4\). A statement of the form \( E(x) \) has a truth value (\textit{true/false}), hence a meaning, whenever the physical object \( x \) is in the state \( S \), if and only if an empirical test can be carried out that specifies this truth value without altering the state \( S \) of \( x \).

In order to distinguish the concept of truth introduced by the standard interpretation of QM from the classical (Tarskian) concept of truth, we say that \( E(x) \) is Q-true (Q-false) in the following whenever \( E(x) \) is true (false) in the sense established by criterion EV.

Criterion EV has some relevant consequences. Indeed, it implies that, whenever \( x \) is given, hence its state \( S \) is known, not all statements of the fragment \( \mathcal{E}(x) \) have a truth value, so that QM is not semantically objective with respect to \( \mathcal{E}(x) \). Moreover, \( \mathcal{E}(x) \) can be partitioned into three subsets, as follows.

- \( \mathcal{E}_S(x) \) : the set of all statements of \( \mathcal{E}(x) \) that are Q-true. One can prove that this set coincides with the set of all statements that are Q-true for every physical object in the state \( S \).
- \( \mathcal{E}^\perp_S(x) \) : the set of all statements of \( \mathcal{E}(x) \) that are Q-false. One can prove that this set coincides with the set of all statements that are Q-false for every physical object in the state \( S \).
- \( \mathcal{E}_I(x) \) : the set \( \mathcal{E}(x) \setminus \mathcal{E}_S(x) \cup \mathcal{E}^\perp_S(x) \) of all statements of \( \mathcal{E}(x) \) that are meaningless, or \textit{indeterminate}.

It follows from the definitions above that the set \( \mathcal{E}_S(x) \cup \mathcal{E}^\perp_S(x) \) is the set of
all statements of $\mathcal{E}(x)$ that have a quantum truth value whenever the physical object $x$ is in the state $S$. \textit{A priori}, the knowledge of $S$ does not imply the knowledge of $\mathcal{E}_S(x) \cup \mathcal{F}_S(x)$. It can be proved, however, that this implication holds in QM. Hence, QM allows one to deduce the truth values of all statements of $\mathcal{E}_S(x) \cup \mathcal{F}_S(x)$, whenever $S$ is given. This means that QM can predict the truth values of all statements of $\mathcal{E}(x)$ that have a truth value according to criterion EV. Thus, we conclude that QM is semantically complete with respect to $\mathcal{E}(x)$.

For the sake of brevity we understand the reference to the fragment $\mathcal{E}(x)$ in the following. Thus, we can comment on the results obtained above by saying that any conclusion about the semantic objectivity and the semantic completeness of QM is strictly linked to the theory of truth that one adopts for the language of QM (of course, this illustrates a general feature of physical theories: a physical theory that is semantically objective, or complete, whenever a given theory of truth is chosen, may be semantically nonobjective, or incomplete, if a different choice is done).

5 Back to EPR

We have seen in Sec. 4 that two different theories of truth for (a fragment of) the observative language of QM underlie the EPR argument and the standard interpretation of QM. It is then apparent that the choice of a Tarskian theory of truth would imply a local and noncontextual interpretation of QM because of semantic objectivity (we have already noted in Sec. 4 that the Tarskian definition of truth does not make any reference to the procedures that can be used in order to know truth values, in particular measurement procedures). This interpretation would avoid a bulk of problems (in particular, those following from nonlocality and pointed out at the end of Sec. 3). One is thus led to wonder why physicists have refused this seemingly plain alternative.

The answer to the foregoing question can be mainly found in the existence of a number of ‘no-go theorems’, the most famous of which are the Bell-Kochen-Specker (briefly Bell-KS) theorem (Bell, 1966; Kochen and Specker, 1967; Mermin, 1993), which is maintained to prove the contextuality of QM, and the Bell theorem (Bell, 1964; Mermin, 1993), which is maintained to prove the nonlocality of QM. Both, of course, imply semantic nonobjectivity of QM. Because of these theorems, any attempt to provide a noncontextual and local interpretation of QM is usually rejected with annoyance by quantum physicists, and considered a naïve misunderstanding of the subtleties of quantum physics.

Nevertheless, the physical meaning of the no-go theorems can be disputed. A critical analysis of it has been carried out by ourselves together with other authors (Garola and Solombrino, 1996a, 1996b; Garola, 1999, 2000, 2002, 2003; Garola and Pykacz, 2004) and it is relevant in our opinion since it opens the way to a new interpretation of QM which adopts a Tarskian theory of truth, hence it is noncontextual and local, in good agreement with EPR’s position. Therefore, let us briefly summarize it.

First of all, let us preliminarily remind that, according to the received view-
point (Sec. 4), every physical theory $T$ states a number of *theoretical physical laws* by using its theoretical language. These laws have no direct empirical interpretation, but one can deduce from them, via correspondence rules, *empirical physical laws*, which are expressed by means of the observative language of $T$ and then associated, via assignment rules, with empirical procedures that allow one to confirm or falsify them.

Let us come now to QM. In order to apply the above scheme to this theory, we must refine the last part of it, since empirical laws cannot be checked in every physical situation according to QM. Indeed, there are physical situations that can be described within the metalanguage of QM but are not *empirically accessible*, in the sense that it is impossible, in principle, to produce empirically a situation of this kind or recognize empirically whether it occurs. If one wonders about the validity of empirical laws within these physical situations, one can choose between two different epistemological positions, that are inspired to ontological realism (OR) and empiricism (E), and that can be loosely synthetized as follows.

**OR.** The mathematical apparatus of $T$ mirrors some kind of physical reality, and theoretical laws parallel (up to some unavoidable approximations) the laws of physical reality. It follows that the empirical laws deduced from theoretical laws are valid in every conceivable physical situation, be it empirically accessible or not.

The above assumption about the validity of empirical physical laws has been called *metatheoretical classical principle*, or MCP, in some previous papers (Garola and Solombrino, 1996a, 1996b; Garola, 1999; Garola and Pykacz, 2004).

**E.** The mathematical apparatus of $T$ is considered as a rational construction that is justified by its ability of connecting and predicting empirical facts. Theoretical laws have no truth value, since they are not directly interpreted, and the empirical laws deduced from them are valid in all accessible physical situations, i.e., in those physical situations in which they can be confirmed or falsified (while they can be valid as well as not valid in nonaccessible physical situations).

The above assumption about the validity of empirical physical laws has been called *metatheoretical generalized principle*, or MGP, in some previous papers (Garola and Solombrino, 1996a, 1996b; Garola, 1999, 2000, 2002; Garola and Pykacz, 2004).

It is rather odd that standard QM, whose verificationist attitude (Sec. 4) is explicitly rooted into antimetaphysical commitments, adopts implicitly position OR when deducing the no-go theorems mentioned above. In order to justify this demanding statement, let us look into this topic in more details by referring to a specific sample case, that is, the Bell-KS theorem (Garola and Solombrino, 1996b; Garola, 2002; Garola and Pykacz, 2004).

The Bell-KS theorem is always proved *ab absurdo* in the literature. One firstly introduces an objectivity condition (O), as follows.

**O.** All physical observables have simultaneous values in all physical situations independently of our knowledge of them.
Then, one introduces the condition that the values of physical observables are consistent with quantum laws (KS condition) as follows.

**KS.** If \( f(A, B, C, \ldots) = 0 \) is an empirical law of QM (where \( A, B, C, \ldots \) denote compatible observables), the values \( a, b, c, \ldots \) of \( A, B, C, \ldots, \) respectively, are such that \( f(a, b, c, \ldots) = 0. \)

Finally, one shows that assuming conditions O and KS together leads to a contradiction. Since condition KS seems to follow directly from QM, hence it cannot be denied without renouncing QM, one deduces that assumption O is untenable within QM. But assumption O is obviously equivalent to the assumption that QM is semantically objective. It follows that QM is a semantically nonobjective, hence contextual, theory (which prohibits the adoption of a Tarskian theory of truth).

The above proof seems conclusive. Nevertheless, if one looks more deeply into it, one sees that the repeated application of the KS condition produces physical situations that are not empirically accessible. Indeed, each empirical law that is applied contains only mutually compatible observables, but there are observables in some laws that are not compatible with observables that appear in other laws. The physical situation in which all these observables have simultaneous values can be conceived but cannot be empirically recognized, hence it is not empirically accessible in the sense specified above. Applying repeatedly the KS condition implies assuming that empirical quantum laws are valid in a situation of this kind, which is legitimate only if one assumes implicitly position OR about the validity of the empirical laws of MQ.

Our analysis has far-reaching consequences. Indeed, it implies that condition KS does not follow directly from QM, since it requires an implicit epistemological assumption about the range of validity of empirical laws to QM. Hence, the contradiction proved by the Bell-KS theorem can be avoided not only renouncing condition O and maintaining condition KS, but also maintaining O and renouncing the validity of empirical laws of QM within nonaccessible physical situations, which amounts to limit the validity of condition KS and say that it cannot, generally, be applied repeatedly (note that this does not invalidate any standard result in QM). It follows that the semantic nonobjectivity of QM is not a logical necessity. Moreover, a similar analysis can be done by referring to the Bell theorem, showing that also nonlocality is not a logical necessity (Garola and Solombrino, 1996b; Garola and Pykacz, 2004). One concludes that, contrary to an almost universal belief, it is possible to envisage new interpretations of QM adopting a Tarskian theory of truth for the observative language of QM. As we have anticipated at the beginning of this section, an interpretation of this kind would avoid the difficulties following from contextuality and nonlocality and would be compatible with EPR’s philosophical position (in particular, it would classify QM as semantically incomplete). The price to pay for this, of course, is accepting a more modest gnoseological role of our physical theories.

We add that the reasonings leading to the no-go theorems (whose mathematical correctness is undisputable) would still be relevant within the new interpretation. Indeed, consider again the specific case of the Bell-KS theorem. The contradiction following from assuming conditions O and KS together would
not show that QM is nonobjective, but that condition KS cannot be applied repeatedly, hence there must be empirical quantum laws that cannot hold within nonaccessible physical situations. This suggests that a physical theory could exist which generalizes QM, reducing to it in all empirically accessible physical situations only.

6 The SR interpretation

An interpretation of QM of the kind envisaged at the end of Sec. 5 has been actually produced by ourselves, together with other authors, in a series of papers (Garola, 1991, 1999, 2000; Garola and Solombrino, 1996a, 1996b). It has been called SR interpretation, where SR stands for semantic realism, since according to it QM is semantically objective, which is compatible with various forms of realism (in particular, with macroscopic realism). The SR interpretation has also been supported by some set-theoretical models that prove its consistency (Garola, 2002, 2003; Garola and Pykacz, 2004).

Of course, the SR interpretation exhibits all features mentioned at the end of Sec. 5, since it adopts a Tarskian truth theory for the observative language of QM. Thus, in some sense, it continues and integrates EPR’s approach, at least from a semantic viewpoint. We maintain that it allows one to solve many problems, avoiding some well known paradoxes of standard QM. In particular, the following results can be attained.

(i) No EPR-like paradox occurs, since QM is a local and noncontextual theory (Garola and Solombrino, 1996b; Garola, 1999).

(ii) The quantum measurement problem is reconsidered and solved in semi-classical terms (Garola and Pykacz, 2004).

(iii) Some suggestions are provided for embedding QM within the more general theory mentioned at the end of Sec. 5.

In addition, our arguments in Sec. 5 lead us to suspect that the difficulties encountered by physicists attempting to attain CM as a limit of QM, or to unify QM and relativity, could have a common cause. Indeed, both CM and (special or general) relativity adopt a Tarskian theory of truth for their observative language, while standard QM introduces, as we have seen in Sec.3, a notion of quantum truth that is not compatible with Tarski’s. Should this conjecture be true, adopting the SR interpretation would eliminate the source of the aforesaid difficulties.

Our conjecture above sounds however rather abstract. But our analysis in Sec. 4 allows us to support it with a more detailed description of some suggestions provided by the adoption of the SR interpretation. Indeed, non-contextuality and locality of QM within this interpretation are attained at the expense of accepting the epistemological position E in Sec. 5, which limits the range of validity of empirical quantum laws (the only empirical consequence of this acceptance should be that in any quantum measurement there are physical objects that are not detected, see Garola, 2003, and Garola and Pykacz, 2004). Analogous limits could then be assumed for quantum field theories in
order to recover noncontextuality, which is a crucial issue, since contextuality is a major obstacle to the unification of QM and relativity. Furthermore, since the SR interpretation is an example of the class of interpretations envisaged at the end of Sec. 4, it suggests that a broader theory embedding QM could be constructed, the laws of which differ from quantum laws only in nonaccessible physical situations. Thus, it is rather natural to think that CM should be a limiting case of this broader theory, which explains the partial failure of the attempts to recover CM as a limiting case of standard QM.

The foregoing suggestions, of course, only sketch a research program, and no one can guarantee that the expected results will actually be found. Yet, our program has the merit, at least, of propounding a new approach to old, unsolved theoretical problems, based on a deep change of physicists’ epistemological attitude rather than on new mathematical techniques and assumptions. Since the standard approach has been only partially successful till now, the new program is worth of attention in our opinion.

We would like to close our paper with a brief remark regarding quantum logic (QL). Indeed, we want to stress that the introduction of an interpretation that adopts a classical theory of truth for the observative language of QM does not mean that QL must be rejected. Rather, it leads to interpret QL as a logical structure formalizing the properties of a metalinguistic concept that does not coincide with truth (to be precise, the pragmatic concept of justification in QM). This interpretation is consistent with the adoption of an integrated perspective, which aims to incorporate classical and nonclassical logical systems into a unified framework that preserves both the globality of logic and the classical notion of truth as correspondence (Garola, 2005).

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NOTES

1. The possibility of distinguishing between theoretical and observative language of a physical theory has been often criticized on the basis of the argument that theory and observation are strictly intertwined. We have already summarized our position about this problem elsewhere (Garola and Sozzo, 2004, footnote 3). Here we remind only that we agree that the choice of the observative language depends on the theory and that also the observative domain can be seen as theory-laden. Yet, we maintain that theoretical and observative language can still be distinguished if one accepts Campbell’s principle (Campbell, 1920), according to which the part of the theory embodied within the observative domain must not depend on the theoretical structure that one wants to interpret (in order to remind this principle, the observative language could also be called pre-theoretical language).

2. The EPR argument can easily be restated in terms of statements of the form $E(x)$. In the specific case considered by EPR, indeed, $x$ may be taken to indicate a sample of the combined system consisting of systems I and II, and statements as “system I has momentum $p$” or “system II has position $r$” can be translated into the statements “$x$ has the property that the momentum of its component system I has value $p$”, and “$x$ has the property that the position of its component system II has value $r$”, respectively, that have the required form. It is then apparent that EPR’s reality condition and locality assumption are compatible with the adoption of a Tarskian theory of truth for $E(x)$ (by the way, we remind that physical properties are usually identified in QM with pairs $(A, \Delta)$, where $A$ is a physical observable and $\Delta$ a Borel set on the real line, see, e.g., Beltrametti and Casinelli, 1981; the properties that appear in our translations can obviously be written in this way).

3. Note that ‘realistic’ completions of QM can be contrived that are nonlocal, as exemplified by Bohm’s theory (Bohm, 1952a, 1952b). Also this theory is compatible with the adoption of a Tarskian truth theory for the observative language of QM. Yet, a statement which attributes a property to a physical object cannot be considered elementary according to Bohm’s theory, and may have no syntactic expression in some physical situations.

4. From an empirical viewpoint, criterion EV introduces the requirement that, before performing a test of the truth value of $E(x)$, one has to prove that the test does not modify the state $S$ of $x$. The empirical procedure that one must adopt in order to fulfill this requirement is not obvious, and it must be worked out by taking into account the laws of QM (Garola, 2005).

5. The assertion that QM is semantically nonobjective can also be based on theoretical and epistemological considerations (indeterminacy principle plus a verificationist position) or on empirical arguments (double slit experiment). Both these approaches, however, are problematical (Garola, 2000), even if the latter is almost universally used in the manuals. The theorems mentioned above, instead, seem to be conclusive because of their mathematical rigour.

6. We maintain that MGP could be formalized by formalizing firstly the observative language of QM and then reconsidering the truth mode of empirical
laws within the framework of a Kripkian semantics. In short, one should define
a non trivial accessibility relation on the set of all possible worlds and assume
that empirical laws are valid only in those worlds that are in the accessibility
relation with the real world. However, we will not discuss this topic in the
present paper.

7 Of course, one could avoid any contradiction also giving up both condition
O and condition KS. We do not take into account this possibility here, since it
does not seem plausible from a physical viewpoint.

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Riassunto. Gli argomenti introdotti da Einstein, Podolski e Rosen (EPR) per dimostrare l’incompletezza della meccanica quantistica (MQ) furono respinti dalla maggioranza dei fisici contemporanei di EPR e non sono accettati nell’interpretazione standard della MQ, secondo cui la MQ è una teoria completa. Se si analizzano le implicazioni semantiche delle due posizioni in conflitto si deduce che esse sottendono due diverse nozioni di verità. L’introduzione di una nozione non classica da parte dell’interpretazione standard è usualmente giustificata facendo riferimento ai noti teoremi che proverebbero che la MQ è necessariamente una teoria contestuale e non locale. Comunque, questi teoremi sono basati su una dubbia assunzione epistemologica implicita. Se tale assunzione viene evitata, è possibile concepire un’interpretazione alternativa all’interpretazione standard che è realistica in senso semantico. Nell’ambito di questa interpretazione è possibile recuperare il punto di vista di EPR, e la MQ è considerata una teoria (semanticamente) incompleta, locale e non contestuale. Inoltre la nuova interpretazione fornisce alcuni suggerimenti per costruire una teoria più generale che incorpori la MQ e per connettere la MQ con la fisica classica e la relatività.

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