The locality of the modified Quantum Mechanics

Abstract.

In this note we shall show the relation between the locality of Quantum Mechanics and the meaning of the quantum state.

1. Introduction

In this note we shall describe the relation between the locality of Quantum Mechanics (QM) and the concept of the quantum state.

At first we shall introduce some terminology which will be used. We shall say that two theories are equivalent if the empirical predictions of these theories are the same (i.e. these theories are empirically indistinguishable). The theory equivalent to the standard QM will be called the version of QM (e.g. the Bohmian mechanics is the version of QM). In ([16] it is shown that the modified QM is a version of the standard QM. Then in [14] different versions of QM are compared among them.

The question of the locality of QM can be answered in three ways

(i) Each version of QM is nonlocal (see [8], [9])
(ii) QM is either nonlocal or non-realistic (see [7])
(iii) QM is local (see e.g. [4])

From [8] it is possible to cite from the abstract: "Bell's 1964 theorem, which states that the predictions of quantum theory cannot be accounted for by any local theory …" and from [9] we can cite "Hence, non-locality is a necessary feature of any theory which shares the empirical predictions of standard quantum mechanics.". These two citations represent the answer (i). The possibility (ii) is the standard consequence of Bell's inequalities (BI), while (iii) is the answer considered by the minority of authors.

The concept of a quantum state is the central topic in foundational studies in QM. The most important contribution to this question can be attributed to von Neumann ([10]):

(i) The state of an ensemble can be described by the density operator in the system's Hilbert space
(ii) An ensemble in the mixed state is not homogeneous
(iii) An ensemble in the pure state is homogeneous

The homogeneous ensemble is defined as an ensemble in which each its member is in the same individual state. The term "individual state" means the state of an individual system – so that the concept of a homogeneous ensemble is equivalent to the concept of the individual state. Statements (i) and (ii) create no controversy (they can be expressed equivalently that some pure states represent individual states).

The statement (iii) is in the center of the discussion. It says that each pure state represent a possible individual state. We shall use terminology from [1], but the question of the completeness of QM will not be considered here. There can be considered different options

(i) ψ-ontic option: each pure state is an individual state (i.e. the von Neumann's statement (iii) above)
(ii) ψ-epistemic option: at least one pure state is not an individual state
(iii) Purely ψ-epistemic option: no pure state represents an individual state
(iv) ψ-hybrid option: some pure states represent individual states while other pure states do not represent individual states (see [12])
(v) Purely ψ-hybrid option: the set of individual states form the orthogonal base of the system's Hilbert space(see [16])

The cases (i), (iii) and (v) are specific while (ii) and (iv) are general. The purely ψ-epistemic option was considered by Einstein [2] and by Ballentine [3] under a name of the statistical interpretation of QM. The ψ-ontic option makes a hidden assumption of the standard QM. The purely ψ-hybrid option makes the basis of the modified QM introduced in the axiomatic form in [16].

We shall show that the choice among (i), (iii) and (v) has the strong influence on the possible locality of QM: (i) implies the possibility to derive (BI), while (iii) and (v) imply the impossibility to derive BI. This fact shows that the standard QM and modified QM are different theories.

In [13] we have presented strong arguments against the ψ-ontic option – we have shown there that the ψ-ontic option can be considered, in some sense, as a hidden error in the standard QM.

The locality of the modified QM requires to show (at least) two properties of the modified QM

(i) BI cannot be derived in the modified QM
(ii) In the modified QM the EPR correlations can be explained locally

The first step was already mentioned [13] and will be explained in details below, while the second step was explained in details at many places – see [11], [15], [16], [17] and [18].

In the second part we shall show in details the impossibility to derive BI in the modified QM and in the last part we shall summarize our results and their consequences.

2. The impossibility to derive BI in the modified QM

Our proof of the impossibility to derive Bell inequalities (BI) in the modified QM will be done in two steps

(i) We show that any derivation of BI requires argumentation based on considerations of individual states
(ii) We show that the set of individual states in the modified QM is too small for the application of any proof of BI

Ad (i)

- The simplest (and the clearest case) is the Mermin's variant of BI [5]. Alice considers three orientations of her measuring system. The key argumentation is the following: with each orientation there is associated an observable with values in {+1, -1}, so that at least two of these three values must be same. Without the consideration of individual states this argument cannot be applied.
- In each other way of proving BI the first step is to look for individual values of some observables. The final statistic is the result of individual cases.

Ad (ii)

- In each derivation of BI there always exists at least one system such that there are considered individual states from at least two different orthogonal bases. But in the modified QM for each system there exists only one bases made from individual states. Thus the derivation cannot be valid.
- E.g. in the case of derivation of CHSH inequality [8] one considers two bases for Alice and two bases for Bob. Clearly, these bases cannot be made from individual states.
- In fact, this argument is the strong form of the argument based on the impossibility of the counterfactual definiteness. In the modified QM there is only one individual base (the term individual base means the base containing only individual states).

The standard way to obtain the nonlocality of some version of QM is based on the derivation of BI. The derivation of BI requires locality, so that assumption of the locality (and perhaps also other assumption of realism) implies the contradiction in QM. If BI cannot be proved then the assumption of the locality does not create the contradiction.

In fact, the modified QM is strictly non-realistic: it is not true that any pure state represents an individual state. In this sense, from the dichotomy "nonlocality or non-realism" in the modified QM the nonrealism is chosen.

It is clear that the option of the meaning of the pure state influences strongly the possibility to derive BI. In the purely ψ-hybrid case (and also in the purely ψ-epistemic case) BI cannot be derived and thus the locality is not threatened.

3. Conclusions and consequences

From the existence of the modified QM and its locality it follows that the statement "each version of QM is nonlocal" cannot be true, since the modified QM is equivalent to the standard QM.

The purely ψ-epistemic option has a disadvantage that in this case there are no individual states. But in the measurement we are surely observing the individual state of the measuring system.

In fact, there are two changes in the modified QM with respect to the standard QM

(i) The purely ψ-hybrid option described above
(ii) The replacement of the concept of measurement by the concept of an observation. But this second change is not relevant for the locality topic considered here. This change allows the solution of the measurement problem since then the measurement process is the internal process in QM (see [16]).

Since there are strong arguments against the ψ-ontic option (see [13]) and since the purely ψ-epistemic option has a disadvantage described above, the modified QM is the best version of QM (see [14]) and should be considered seriously.

The locality of the modified QM is its great advantage with respect to the standard QM. The other advantages of the modified QM can be found in [14].

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