The logical error in the derivation of the non-locality

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Abstract

In this paper we shall show that the standard derivation of the non-locality contains the logical error which invalidates the whole derivation.

The derivation of non-locality.

It is well-known that the non-locality is considered as the main consequence of Bell Inequalities (BI) – see [1], [2], [3], [4], [5], [6], [7], [8] for different aspects of BI. For example the title of [1] is "Bell nonlocality". BI are interconnected with EPR correlations in Quantum Mechanics (QM).

Below we shall use the simple notation for logical operators (*and*, *or*, *not*, *implies*) instead of the purely logical notation used in logic.

The standard derivation of non-locality proceeds through the following steps

(1) (locality *and* QM) *implies* BI

(2) (BI *and* QM) *implies* contradiction

As a consequence we obtain the non-locality.

There are hidden assumptions in this derivation which must be clarified. Let

(3) $Ax_1, \ldots, Ax_n$

be axioms of QM. These axioms are not explicitly mentioned in the derivation above and this creates a problem.

The correct derivation must have the following form

(4) (locality *and* Ax_1 *and* ... *and* Ax_n) *implies* BI

(5) (BI *and* Ax_1 *and* ... *and* Ax_n) *implies* contradiction

As a consequence we obtain

(6) (locality *and* Ax_1*and* ... *and* Ax_n) *implies* contradiction

and then

(7) *not* (locality *and* Ax_1 *and* ... *and* Ax_n).

This is equivalent to

(8) non-locality *or not* Ax_1 *or ... or not* Ax_n.

This means that

either QM is non-local or at least one of axioms Ax_1, ..., Ax_n is false.

Simply this means that not only locality may be false, but that any axiom of QM may be false, too. There may be the situation, where the rejection of some axiom of QM will not create the big problem – while the rejection of locality creates the true disaster in physics in general.

In fact, the set of axioms $Ax_1, \ldots, Ax_n$ can be effectively restricted to its subset

(9) $Ax_1, \ldots, Ax_m$, for some m smaller or equal to n

which contains only those axioms which are needed in the derivation of (4) and (5).

So the correct consequence says that

either QM is non-local or at least one of axioms $Ax_1, \ldots, Ax_m$ is false.

Thus the non-locality is not a necessary consequence of BI and the standard derivation is then incorrect.

What was overlooked is the fact that also some axiom of QM may be false (details will be given below). Also the interpretation of QM is not fixed in general and this may play its role - for example in [2] the author gives arguments for the locality of QM in the many-worlds interpretation.

The hidden assumption consists in the idea that axioms $Ax_1, \ldots, Ax_n$ are a priori true.

Another point of view

All written above can be reformulated in a way which could make our idea clearer.

Let us denote the assumption of locality as Ax_0 and let us consider the extended quantum mechanics extQM as the theory with axioms

$$Ax_0, Ax_1, .., Ax_n$$

This is not a wrong idea to consider the theory as extQM: in general, axioms should be statements which are intuitively true (in a given segment of science) and the assumption of the locality is intuitively true. (One could even consider the locality as a necessary axiom of any physical theory.)

But then it is possible to derive BI in extQM and to obtain a contradiction. This implies that some axiom from $Ax_0, Ax_1, \dots, Ax_n$ must be false. The conclusion is the same as above: either physics is non-local or some axiom of QM is false.

Must be all axioms of QM true ?

At first, there is an argument that the great experimental success of QM implies that axioms of QM must be true. But such an argument is a logical mistake. The purely logical form of this pseudo-argument is the following paradox: if A implies B and if B is true, then what can be asserted on A ? (The concrete example: if it is raining in Prague, then Prague is bigger than Brno – what can be concluded about the rain in Prague ?)

Let $R_1, \dots, R_s$ denote all experimentally tested consequences of QM and let us assume that there does not exist a member among $R_1, \dots, R_s$ which contradicts to the experiment. In this situation it is not possible to assert that axioms $Ax_1, \dots, Ax_n$ of QM are true. The only possible conclusion is that QM cannot be refuted.

Let us consider a theory QM‘ different from QM such that the set of all experimentally tested consequences of axioms from QM’ is the same set $\{R_1, \dots, R_s\}$. Then it may happen that some axiom of QM is false, while all axioms of QM’ are true.

Thus the complete experimental success of QM does not imply that all axioms of QM must be true.

All this is connected with the fact that only some consequences of QM may be tested, not all.

It may seem that the logical considerations in this paper are overdone. But the general experience says that when some theory is approaching the inconsistency, then the arguments must be extremely precise and exact.

Now we shall analyze the situation more concretely.

This type of situations was already considered in papers [9] and [10]. We shall specify the axiom of QM which is the candidate for the false axiom. This is the axiom which we consider as the basic assumption formulated by John von Neumann

(Ax_{vN}) each pure state can be the state of some individual system.

Equivalently this can be expressed in the form that each ensemble which is in the pure state is homogeneous (i.e. such that all members of this ensemble are in the same state). This axiom implies clearly the principle of superposition for individual systems.

In [9] there was proposed the opposite assertions – the principle of anti-superposition and we propose here the anti-von Neumann axiom

The principle of anti-superposition says that no non-trivial superposition of two states of the individual system can be a possible state of the individual system (see [9]).

The **anti-von Neumann axiom** proposed here states the following

(Ax_{avN}) each two different states of the individual system must be orthogonal.

The anti-von Neumann axiom clearly implies the principle of anti-superposition.

Let us assume that Ax_{vN} is one of the axioms of QM, say Ax_1, so that QM is defined by axioms $Ax_{vN}, Ax_2, \ldots, Ax_N$.

Then the modified QM (modQM) introduced in [9] may be defined by axioms (the von Neumann axiom is replaced by the anti-von Neumann axiom)

$$AX_{avN}, Ax_2, \ldots, Ax_n{}^1$$

Then it is shown in [9] that the set of results of QM is the same as the set of results of modQM with only one exception: BI are derivable from standard QM + locality, while BI are not derivable from modQM + locality.

But this means that all practical results of QM are the same as all practical results of modQM (see [9]). This means that QM and modQM are experimentally indistinguishable.

It is shown in [9] that modQM is local at least in the sense of following statements

(i) in modQM there exists a local explanation of EPR correlations

(ii) in modQM it is impossible to derive BI.

(iii) modQM + locality is the consistent theory

Usually it is considered the alternative: non-locality or non-realism. The problem with this alternative consists in the fact that the realism (or non-realism) was never clearly (and uniquely) defined (see [5]).

We assert that Ax_{vN} has something to do with the realism (and Ax_{avN} with non-realism). For example Ax_{vN} states that each pure state can be attributed to some individual system. In modQM it is possible to specify in which sense modQM is non-realistic – this is clear from the description of the measurement process in modQM (which is the intrinsic process in modQM and not extrinsic like in QM) - see details in [9]. What is sure is the fact that in modQM the EPR criterion of reality is false.

[1] In fact, this formulation is too schematic, there are needed also other changes, but they have rather technical character (for details see [9]).

We have seen that there are two alternatives

(i) QM with non-locality and realism

(ii) modQM with locality and non-realism

One could have an idea that these two alternatives can be considered as equally possible.

But it is not true. In [10] it is shown that in the case (i) it is not possible to solve the problem of the inconsistency of quantum theory, while in the case (ii) the quantum theory remains consistent. This means that modQM should be preferred.

Conclusions.

(i) the standard derivation of non-locality from BI is not correct (it contains hidden assumptions)

(ii) the possibility that some axiom of QM may be false is overlooked

(iii) modified QM offers the alternative, since it is local and has the same experimental consequences as QM

(iv) using modQM it is possible to save the consistency of quantum theory

(v) using modQM the locality of physics can be saved

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