On a gap in the derivation of the Bell nonlocality

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Abstract. In this note we shall show that the proof of the nonlocality of Quantum Mechanics given in [1] contains a gap. We also show that Bell inequalities cannot be derived in the modified QM.

In the paper [1] there is a proof of the nonlocality of Quantum Mechanics (QM). In the proof of this statement the main step is the following implication: "from EPR correlations to the predetermination". This means the following:

- "A deterministic hidden variable theory was one's only hope, if one wanted to explain the predicted quantum correlations in a local way." ([1]. Page 2) – i.e. the nonlocality or the pre-determination.
- "The important thing was instead that the only way to explain the perfect correlations locally is to attribute outcome-determining properties to the individual particles. These properties, evidently, would vary randomly from one particle pair to the next, but would be fixed (in an appropriately correlated way) once and for all at the source for a given particle pair." ([1], page 2). This may be called the pre-determination.
- "… such deterministic hidden variables are the only way to account locally for the perfect correlations" ([1], page 3).

The same argument is also contained in [2] and [3].

The author of [1] asserts that the unique possibility to explain locally the EPR correlations is the pre-determination.

We shall show that this assertion is false. We do this by presenting another local explanation of EPR correlations.

Let us consider systems **S** and **R** which are in the standard entangled singlet state

$$\psi = 2^{-1/2} \left(|S1\rangle \otimes |R0\rangle - |S0\rangle \otimes |R1\rangle \right)$$

and let **A** be a measuring system at the region of Alice and let **B** be a measuring system at the region of Bob.

The measuring system **A** has the basis |A1⟩, |A0⟩ where these two states are individual states and let us assume that in the standard (von Neumann) measurement the state |A1⟩ is linked to the state |Sφ1⟩ of the measured system **S** and the state |A0⟩ is linked to the state |Sφ0⟩ (where φ denotes the orientation of the measuring system). The system **S** has individual states |S1⟩, |S0⟩ and states |Sφ1⟩, |Sφ0⟩ are not individual states but collective states, i.e. states of ensembles. The same for Bob, i.e. |B1⟩, B0⟩, |Rφ1⟩, |Rφ0⟩ and Bob`s measurement links |B1⟩ with |Rφ1⟩ and |B0⟩ with |Rφ0⟩.

Now we apply the process which is local at each step.

(i) We transport the system **S** to the region of Alice and we transport the system **R** to the region of Bob
(ii) Alice connects her system **A** in the state |A0⟩ to the system **S** and applies the measuring transformation to the system **A + S** following the linking described above – we then obtain the state described in the eq. (3C12) in [4]. This process is local since it connects only systems **A+S** which are localized in the region of Alice.
(iii) Bob connects his system **B** to the system **R** and applies the corresponding measuring transformation; the resulting state of the system **A+S+R+B** is described by the eq. (3C13) and (3C14) in [4].
(iv) In the situation when Bob applies the same measurement as Alice then the state reduces to the state described by eq. (3C15) from [4]. This is not the process but the specification of orientations of measuring systems **A** and **B**.

Now one can do the mathematical calculations represented in eq. (3C16) and (3C17) with the result described by the eq. (3C18) from [4]. The eq. (3C18) implies the perfect anti-correlation of the outputs of **A** and outputs of **B** as it is expressed in eq. (3D1).

This explanation of the anti-correlation between **A** and **B** described above in steps (i) – (iii) is completely local. Thus in this way we have obtained the local explanation of the EPR correlation. The other steps consist in purely mathematical calculations.

The correlation between **A** and **B** is analogous to the classical correlation between two bits with the probability distribution given by $P(A0, B0) = P(A1, B1) = 0$ and $P(A1, B0) = P(A0, B1) = ½$. This classical correlation is completely local. The specific feature of QM consists only in the fact that in QM this classical correlations is obtained for each orientation φ of measuring systems **A** and **B.**

We have obtained a new local explanation of the EPR correlations different from the explanation based on the pre-determination.

This implies that the assertion in the paper [1] cited above (nonlocality or pre-determination) is not true.

It is important to understand that the perfect anti-correlation between measuring systems **A** and **B** does not imply the same perfect anti-correlation between individual systems **S** an **R**.

The perfect anti-correlation between **S** an **R** exists only on the level of ensembles but not on the level of individual systems. All this is explained in details in [4].

Thus the whole derivation of nonlocality in [1] is not correct since the main step "nonlocality or pre-determination" is false.

To make the locality of QM possible it is necessary, moreover, to show that Bell inequalities cannot be derived.

To do this it is necessary to use concrete modification of QM. I shall use the modified QM introduced in [4] and axiomatically defined in [5]. The basic idea is that not all pure states can be considered as individual states but only a particular orthogonal base can be considered as the set of individual states (so-called anti-von Neumann axiom: two different individual states must be orthogonal – see also[6]).

Thus in the modified QM individual states form the particular orthogonal base and other pure states are states of ensembles. Then it is clear that Bell inequalities cannot be derived in the modified QM. In each derivation of Bell inequalities states from at least two different orthogonal bases are used (see [6], meta-theorem B). But the derivation of Bell inequalities is based on the consideration of individual states. Thus Bell inequalities cannot be derived in the modified QM.

Thus the locality of modified QM cannot be excluded. This means that the locality of the modified QM should be accepted.

Conclusions

We have shown that the proof of the nonlocality of QM presented in [1] is not correct and we have given a new local explanation of EPR correlations which is not based on the pre-determination.

References

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