Quantum mechanics vs. local realism, is that the question?

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Abstract
The conjecture is made that quantum mechanics is compatible with local hidden variables (or local realism). The conjecture seems to be ruled out by the theoretical argument of Bell, but it is supported by the empirical fact that nobody has been able to perform a loophole-free test of local realism in spite of renewed effort during almost 40 years.

During the last three decades many experiments have been performed aimed at ruling out any local hidden variables (LHV) theory. In spite of the effort some deficiencies in the proof remain, the most important being described by locality and detector efficiency loopholes. According to recent reports the two loopholes have been closed \cite{1,2}. However, each loophole has been closed in a different experiment. That this is not enough to refute all LHV theories has been pointed out by Vaidman \cite{3}. I agree with that paper except for a point which will be commented below. Therefore I shall not spend time in repeating the arguments, which may be summarized as follows: The existence of a loophole means that quantum mechanics and LHV are actually compatible for the experiment and, therefore, the experiment is unable to discriminate between quantum mechanics and LHV theories. The fact that quantum predictions are verified, certainly reinforces our belief in the correctness of quantum theory. But the experiment says nothing against LHV theories.
The opinion of Vaidman, and many other people, with which I disagree is expressed in his sentence: "there is no real question what will be the outcome of this type of (loophole-free) experiments: the predictions of quantum theory or results conforming with the Bell inequalities. ...only a minute minority of physicists believe that quantum mechanics might fail in this type of experiments.” I would not disagree with the sentence if I were willing to accept the alternative “either quantum mechanics or LHV theories”, but I do not accept it, as explained below.

After the discovery of the steam engine in the XVIII Century, many people attempted to construct a "perpetuum mobile", that is a machine able to work for ever either without energy supply or extracting energy by just cooling the environment. They failed, and this lead physicists to postulate that the "perpetuum mobile" is impossible, which on turn is the basis for the principles of thermodynamics. Now, for almost 40 years, many people have tried to perform a loophole-free Bell test, and they have failed. (By way of comparison we may recall that after the proposal by Lee and Yang that parity is not always conserved, this was proved in an uncontroversial (loophole-free) experiment by Wu et al. in less than one year). Consequently it is not so absurd if I conjecture that loophole-free Bell tests are impossible.

If we leave outside theoretical arguments, we have two empirical facts: 1) The predictions of quantum mechanics have been verified in many experiments with unprecedent precision, 2) No loophole-free Bell test has yet been performed. Therefore there is a real open question, namely to confirm or disprove the conjecture above stated. A single loophole-free experiment violating a Bell inequality would show that the conjecture is false. But after every attempt at performing such an experiment fails the conjecture becomes reinforced. This is similar to the reinforcement of quantum theory after every experiment that verifies its predictions.

The compatibility between quantum mechanics and LHV theories, not yet disproved empirically, contradicts the theoretical argument known as Bell’s theorem. Therefore, might be the case that Bell’s theorem is false? In order to answer this question we firstly remember that any theorem is a mathematical statement whose relation with empirical facts is not straightforward in general. In quantum mechanics there are two quite different ingredients, namely the formalism (that is the equations) and the (”semantical”) rules for the connection with experiments (for instance, the assumption that all states which may be actually prepared in the laboratory can be represented by density operators on Hilbert space). I do believe that the equations of quantum
theory are correct, but I think that the standard semantical rules may be questioned. It is the case that the most spectacular verifications of quantum theory (e.g. the value of the Lamb shift or the magnetic moment of the electron) depend strongly on the equations but very weakly on the semantical rules. In sharp contrast, the proof of Bell’s theorem depends strongly on the semantical rules. I explain the point in more detail in the following.

The standard proof of Bell’s theorem requires assuming the existence of the singlet state of two spin-1/2 particles. Quantum theory predicts a violation of the Bell inequality if the spin projections of the particles in this state are measured at spacelike separation. But, without changing in any way the quantum formalism, we might assume that the singlet pure state cannot be prepared in the laboratory. For instance we may suppose that only those states of two spin-1/2 particles (in a 4-dimensional Hilbert space) whose density matrix fulfils $\text{Tr}(\rho^2) < 1/2$ may be actually prepared. It is not difficult to show that such states never violate a Bell inequality. That assumption is too strong and probably false, but it might be the case that, even if the pure singlet state can be prepared, it evolves in such a way that the spin correlation decreases with time, e.g. due to the fact that in Dirac’s theory the spin and the orbital angular momentum are not separately conserved. (The situation is different with light, where the polarization correlation is not lost with time [4],[1]). Or it might be that the combination of spin correlation and position correlation decreases in such a way that the Bell inequality can never be violated. The reader is probably convinced that all these possibilities are rather unlikely, but then I put him/her the challenge of explaining why it is so extremely difficult to perform a loophole-free Bell experiment. I do not have an explanation for the case of the spin-1/2 particles, but I have one for the most common kind of experiments used to test Bell’s inequalities, namely those using correlated photon pairs produced in parametric down conversion (PDC) [3]. It is the case that most of the ”violations of a Bell inequality” reported in the last 20 years have used PDC (and suffer from the efficiency loophole).

In summary, I do not think that the question to be answered by future experiments is whether quantum mechanics or local realism is true, but whether there is a real contradiction between them or not.

References
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