Has CHSH-inequality any relation to EPR-argument?

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Abstract

We emphasize the role of the precise correlations loophole in attempting to connect the CHSH type inequalities with the EPR-argument. The possibility to test theories with hidden variables experimentally by using such inequalities is questioned. The role of the original Bell inequality is highlighted. The interpretation of the CHSH inequality in the spirit of Bohr, as a new test of incompatibility, is presented. The positions of Bohr, Einstein, Podolsky, Rosen, Bell, Clauser, Horne, Shimony, Holt, and De Broglie are enlightened.

1 Introduction

The recent success in performing clean and loophole free experiments [1, 2, 3] testing violations of the Bell-type inequalities can make the impression that the long debate on interpretation of violation of these inequalities has been finally ended. Moreover, some authors, e.g., [4, 5], consider these experiments as the final accords in the long debate between Einstein and Bohr. Such authors couple these inequalities with the Einstein-Podolsky-Rosen (EPR) framework [6], cf., however, [7, 8]. Nowadays it is widely claimed that “Bohr was right and Einstein was wrong”. It is interesting that this formulation peacefully coexists with the statement that experiment
confirms “quantum nonlocality. The aim of this note is analyzing the After-Bell situation in quantum foundations, see also [8].

2 Does CHSH inequality have any relation to the EPR framework?

I claim that the answer to this question is negative. The key point of the EPR framework is consideration of precise correlations and coupling them with EPR elements of reality. In particular, the EPR statement on quantum nonlocality (as an absurd alternative to incompleteness of QM) has meaning only this framework. Those few who read the original Bell’s paper [9], see also [10], know that here Bell tried to mimic the EPR framework [6] by using hidden variables. However, the quantum counterpart of initial Bell’s scheme was based on theoretical possibility of preparation of singlet states. At that time preparation of ensembles of high quality singlet states was totally impossible. Bell understood well that his original inequality which was derived under assumption of perfect (anti-)correlations cannot be tested experimentally. And he was happy to join Clauser, Horne, Shimony, and Holt who used a new scheme and derived CHSH-inequality [11]. It seems that in future Bell had never mentioned [10] his original inequality derived in 1964, the original Bell inequality. The CHSH-scheme is not based on consideration of precise (anti-)correlations. It provides the possibility of performing experiment, even without clean technology for preparing singlet states.

Experimenting with the CHSH inequality [11] and inequalities based on the same scheme [12,13,14,15] was extremely stimulating for development of quantum technologies. It was also one of biggest challenges for experimenters in history of physics. Therefore it is impossible underestimate the value of the CHSH-type inequalities for physics. However, we have to be honest and say explicitly:

The CHSH inequality and other inequalities which are not based on precise correlations have nothing to do with the EPR framework and the Einstein-Bohr debate.

Hence, statements as “Closing the Door on Einstein and Bohr’s Quantum Debate”, see [4], are not justified. To close this door, the original Bell inequality [9] as to be tested. Nowadays the experimental technology is essentially more advance than in Bell’s time. In particular, very clean ensembles
of singlet states can be prepared. Photo-detectors of high efficiency were already used in quantum experiments. This makes the experiment on violation of the original Bell inequality at least less impossible than in Bell’s time, see [16] for detailed analyzing the interplay between detection efficiency and the singlet state preparation. Obviously, such an experiment is even bigger challenge for experimental physics than the previous experiments on violations of inequalities based on the CHSH scheme.

3 Would be Bohr happy with nonlocal “closing the door” in his debate with Einstein?

From reading Bohr [17] and philosophers who put tremendous efforts to clarifying Bohr’s views, e.g.,[18], we understand that for him quantum mechanics (QM) is a local theory. In particular, he did not explore the nonlocality alternative in his reply to Einstein [19]. It is practically unknown that Bohr also had his own notion of an element of reality known as phenomenon. And this is a local notion, see [20].

Hence, the talks of people claiming they are Copenhagenists and at the same time speaking about quantum nonlocality are really misleading. They should honestly reject the Copenhagen interpretation and explicitly say that not only Einstein, but also Bohr and other members of the Copenhagen school were wrong, because they were sure in quantum locality.

4 Incompatibility or nonlocality?

By Bohr the complementarity principle is the fundamental principle of QM. Experimentally this principle is expressed in existence of incompatible observables. Such observables cannot be jointly measured. Historically Heisenberg’s uncertainty relation for the position and momentum observables was Bohr’s starting point. In his reply to the EPR argument [19] Bohr emphasized the role of the complementarity principle. By him the EPR argument does not bring anything new to quantum foundations. He stressed that the complementarity principle is about the position and momentum of a single particle. And quantum interference experiments, as the two slit experiment, demonstrate incompatibility of these observables. Bohr did not find anything new in the EPR-argument. For him, quantum interference is the basic mystery
of quantum mechanics. There is no need in “additional mysteries” such as quantum nonlocality.

The CHSH equality and other Bell type inequalities which are not based on precise correlations are just additional statistical tests for the complementarity principle. In the CHSH scheme, there are considered four observables $A_i$ and $B_i$, $i = 1, 2$, such that $[A_i, B_j] = 0$. Hence, pairs $A_i, B_j$ can be measured jointly and the corresponding correlations $\langle A_i B_j \rangle$ can be calculated. They violate the CHSH inequality for some state if and only if $[A_1, A_2] \neq 0$ and $[B_1, B_2] \neq 0$, i.e., the $A$-observables as well as the $B$-observables are incompatible, cf. with Bohr’s reply [19] to EPR paper [6]. This incompatibility is crucial in the CHSH framework.

For Bohr, violation of the CHSH inequality is just a tricky form of expression of interference between projections of spin or polarization on different axes.

5 EPR-framework: a loophole from subquantum world to quantum experiment

Bohr’s reply to Einstein is often commented as unclear and misleading. And there is a point. We can wonder: How can complementarity help in explanation of the perfect correlations? In no way! But, for Bohr, there was no need in “explanation” of their origin. QM is an operational formalism concerning measurement outputs. The formalism predicts the existence of the EPR-states. And, for Bohr, this is the final point of the scientific treatment of this problem.

However, these correlations are intriguing and some people are seeking their explanation. Of course, such an explanation can be generated only in some subquantum theory. What is the key point of the EPR-argument? This is coupling of elements of such a hypothetical subquantum theory with measurement outputs, the elements of reality with outputs of measurements for the EPR-states. In principle, this coupling can be used as a loophole in the Copenhagen doctrine. One can try to test the predictions of hypothetical subquantum theories. But such tests are meaningful only for the EPR-states as, e.g., the singlet state.
6 Can the CHSH-scheme be used to test experimentally hidden variable theories?

I claim that the answer to this question is negative. Here “experimentally” is the crucial word. As was repeatedly pointed out, the CHSH-inequality is not about precise correlations. Therefore we cannot use the EPR loophole from the subquantum world to quantum experiment. There is no reason to assume that subquantum correlations expressed mathematically in terms of hidden variables coincide with the experimental correlations predicted by QM. The correlations given by integrals with respect to the distribution of hidden variables satisfy the CHSH-inequality, but generally they have no relation to correlations obtained in experiment. In fact, this was De Broglie’s viewpoint, see [21, 8]. This viewpoint match the Bild conception of scientific theory which elaborated by Hertz and Boltzmann, see [22].

7 Concluding remarks

The main impact of experimental testing for CHSH-like inequalities is demonstration that correlations predicted by QM can be preserved for very long distances. The only foundational impact of such tests is the confirmation of Bohr’s complementarity principle. Such inequalities and tests on their violation cannot be used for testing hypothetical subquantum theories with hidden variables. It seems that only the original Bell inequality can be used for such a purpose. Until a loophole free test for the latter will be performed, the statements as “Bohr was right and Einstein was wrong” or “Closing the door on Einstein and Bohr’s quantum debate” are not justified.

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