Bell Inequalities, Wave-Particle Duality, and Quantum Computing

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Abstract
Let us consider the Bell experiment using photons in a laboratory. We may see the violation of a Bell inequality. We give a conjecture for a deterministic interpretation of quantum measurement outcome in the case. We discuss some situations that Quantum Mechanics is a deterministic theory. Also we comment on the debate of Einstein and Bohr. It turns out that both of them are correct.

Keywords: Bell inequalities, the wave-particle duality, a deterministic interpretation of quantum measurement outcome, quantum computing

1. Introduction

Quantum Mechanics is extremely difficult to understand. What is the wave-particle duality? We may not say the final understanding with the usual explanation of the violation of a Bell inequality [1]. Are there hidden variables within Quantum Mechanics? We see the valuable debate between Niels Bohr and Einstein [2,3]. What is the meaning of the violation of a Bell inequality?

An application of Quantum Mechanics says quantum information theories. Quantum computing science is studied very much. It is desirable that Quantum Mechanics is a deterministic theory because we want to get a deterministic answer. The present quantum computing gives a probability of it.

Recently it is discussed that a mathematical inconsistency occurs within Bell inequalities. The inconsistency is similar to a mathematical incompleteness [4]. The fact says the possibility that hidden valuables may exist and Quantum Mechanics may be a deterministic theory. It is desirable situation for quantum computing.

It is discussed that a new measurement

theory, in qubits handling, based on the truth values, i.e., the truth T (1) for true and the falsity F (0) for false. The results of measurement are either 0 or 1 [5]. The good point is the fact that the new measurement theory accepts hidden variables when we measure a single qubit [6]. It is a deterministic theory.

However, we definitely accept that there is not any inconsistency in a laboratory Bell experiment. An extremely unbalanced measurement result is given. The fact is true [7,8,9]. But we may not discuss the true meaning of the experimental violation of Bell inequalities at this stage.

In the short communication, we review foundations of Quantum Mechanics. We give a conjecture for a deterministic interpretation of quantum measurement outcome. We discuss some situations that Quantum Mechanics is a deterministic theory. Finally we comment on the debate of Einstein and Bohr.

2. Foundations of Quantum Mechanics and Conjecture

We may review the following statements.

Statement: Particle and Wave quality are in an entangled way present in a photon. Before we measure a photon, it obeys the wave quality. Once we measure a photon the value of quantum measurement becomes a constant. And the quality becomes particle. Then the wave quality vanishes.

Statement: There is a flaw within Bell inequalities because it is mathematically incomplete. The statement is very important because Quantum Mechanics may be a deterministic theory.

Statement: When we measure many photons, the phenomenon approaches to classical manner. We see the macroscopic physics obeys Newton's laws.

Statement: We may see the violation of a Bell inequality in a laboratory experiment.

In what follows, we may discuss a meaning of the violation of a Bell inequality in a laboratory experiment.

Bell inequality: The violation of a Bell inequality in a laboratory experiment implies the wave quality exceeds the particle quality. Essentially, the common quantum principle needs the wave quality.

Here we write down the following conjecture below.

Conjecture: Let us consider the Bell experiment using photons in a laboratory. Quantum measurement outcome is deterministic and has the following meaning.

The absolute value of a quantum measurement outcome is $\frac{\text{Wave quality}}{\text{Particle quality}}$.

We give some explanations of the conjecture as follows.

1. If the Wave quality is 1 and the Particle quality is $\sqrt{2}$, then Bell inequalities may not violate. In the case the experimental physical phenomenon may admit local realistic theories [10,11], that is, admit a deterministic theory.
2. If the Wave quality is equal to the Particle quality then we may see the violation of Bell inequities in a laboratory experiment (J. von Neumann's projective measurement [12]). The case is common.
3. If there is not Wave quality and Particle quality exists then we do not see any violation of Bell inequalities in a laboratory experiment. In the case the physical phenomenon is classical and Quantum Mechanics is a deterministic theory.

Summing up, we conclude Quantum Mechanics is a deterministic theory if we accept the conjecture.

It is very interesting to study the relation between the conjecture described above and the measurement theory based on the truth values [5,6].

3. On the Debate of Einstein and Bohr

Einstein, Podolsky, and Rosen (EPR) discuss that a hidden-variable interpretation of Quantum Mechanics (a deterministic theory) is essence. On the other hand, Bohr replies that there are not any flaws in the present Quantum Mechanics.

Here we comment that both of them are correct by depending physical situations below. Suppose a qubit. If the state is a pure state |0> then the result of measurement is 0. Thus we may accept the EPR in the case. (Wave quality may not exist in the case.) If the state is in quantum superposition a|0>+b|1> then the result of measurement is 0 with the probability $|a|^2$ and 1 with the probability $|b|^2$. Thus we accept Bohr in the case. (Wave quality may exist.)

Is Quantum Mechanics a deterministic theory? We can answer it is yes at this stage.

4. Conclusions

In conclusion, we have considered the Bell experiment using photons in a laboratory. We may have seen the violation of a Bell inequality. We have given a conjecture for a deterministic interpretation of quantum measurement outcome in the case. We have discussed some situations that Quantum Mechanics is a deterministic theory. Also we have commented on the debate of Einstein and Bohr. It has turned out that both of them are correct.

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References

[1] J. Bell, “On the Einstein Podolsky Rosen Paradox” Physics, 1 (3): 195 (1964).

[2] A. Einstein, B. Podolsky, and N. Rosen, “Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?” Physical Review 47, 777 (1935).

[3] N. Bohr, “Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?” Physical Review 48, 696 (1935).

[4] H. Geurdes, K. Nagata, T. Nakamura, and A. Farouk, “A note on the possibility of incomplete theory” arXiv:1704.00005 [physics.gen-ph] (2017).

[5] K. Nagata and T. Nakamura, “Measurement Theory in Deutsch’s Algorithm Based on the Truth Values” International Journal of Theoretical Physics, Volume 55, Issue 8, 3616 (2016).

[6] K. Nagata and T. Nakamura, “A classical probability space exists for the measurement theory based on the truth values” Quantum Studies: Mathematics and Foundations, Volume 4, Issue 1, 7 (2017).

[7] A. Aspect, P. Grangier, and G. Roger, “Experimental Tests of Realistic Local Theories via Bell’s Theorem” Physical Review Letters 47, 460 (1981).

[8] A. Aspect, P. Grangier, and G. Roger, “Experimental Realization of Einstein-Podolsky-Rosen-Bohm Gedankenexperiment: A New Violation of Bell's Inequalities” Physical Review Letters 49, 91 (1982).

[9] A. Aspect, J. Dalibard, and G. Roger, “Experimental Test of Bell’s Inequalities Using Time-Varying Analyzers” Physical Review Letters 49, 1804 (1982).

[10] K. Nagata and T. Nakamura, “Analysis of Bell-Type Experiments and Its Local Realism” Journal of Applied Mathematics and Physics, Volume 3, No.7, 898 (2015).

[11] K. Nagata and T. Nakamura, “An additional condition for Bell experiments for accepting local realistic theories” Quantum Information Processing, Volume 12, Issue 12, 3785 (2013).

[12] J. von Neumann, “Mathematical Foundations of Quantum Mechanics” (Princeton University Press, Princeton, NJ, 1955).