EPR thought experiment in mirror argumentation

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Introduction

EPR proposed thought experiment leads one to the conclusion that quantum theory is incomplete. Since, on the one side, the authors' line of reasoning seems to be flawless, and, on the other side, the quantum theory does not exhibit any hints on its incompleteness, one obtains the *EPR* paradox.

In present work we shall try show that the *EPR* paradox arises due to not quite correct line of reasoning, when analyzing the proposed thought experiment. A consequent analysis of this thought experiment is in full agreement with the predictions of quantum theory and does not cast a shadow on its validity.

Objections against *EPR* assumptions and their line of reasoning

Our main objections are addressed to *EPR criterion of reality*, *interpretation of an eigenstate, construction and interpretation of a quantum state of a composed system.*

EPR criterion of reality: "if, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity."

If understood in its literal sense, this criterion (even as sufficient one) is inconsistent. Because, it asserts that what is real or objective is determined by a theory. However, a theory describes phenomena - that what we observe. In this sense its predictions are nothing else as eventual phenomena which it pretends to describe and which must be experimentally verified. Thus, a theory itself doesn't lead us beyond the scope of phenomena and, hence, its predictions can not be guarantee about that what is real.

Interpretation of an eigenstate. According to EPR, *"if $|\psi_a\rangle$ is the eigenfunction of the operator $\hat{A}$, then the physical quantity A has with certainty the value a."*

This claim is not so well grounded to be considered as a self-evident truth. Namely, quantum mechanics only predicts that in this case the value a with certainty will be found in the measurement, and *not* that it already exists as a physical reality. Even the eigenstate $|\psi_a\rangle$ measurement requires a full range of the observable $\hat{A}$ measurement procedure in which from all possible alternatives is realized only one. I.e., although the eigenstate $|\psi_a\rangle$ is characterized by the single, definite observable eigenvalue a, it does not mean that the physical quantity A exists as a physical reality by analogy with classical physics, when it can be attached to a physical system directly without intercession of a state vector.

Construction and interpretation of a quantum state of a composed system. According to *EPR* the state vector of the combined system 1+2 after interaction can be expressed as

$$|\Psi\rangle = \sum_{n=1}^{\infty} |u_n\rangle|\psi_n\rangle. \tag{1}$$

The authors assume that the state vector $|\Psi\rangle$ is a rather general mathematical object, the explicit structure of which depends on the externally and arbitrary chosen observables for the subsystems.

It is not quite correct. According to quantum mechanics, every state vector is explicit in a sense that it has particular decomposition over the eigenstates characterized by a set of quantum numbers, which are the eigenvalues of a definite set of commuting observables determined by a system's Hamiltonian or symmetry considerations. Hence, it inwardly determines the set of according measurements. That regards also the case of the composed system, in particular, the EPR pair. Let us assume that $|\Psi_n\rangle$ are the eigenstates of some observable $\hat{A}$, pertaining to the EPR pair system, while $|\psi_{n_1}\rangle$ and $|\phi_{n_2}\rangle$ are the eigenstates of the same type of observables $\hat{A}_1$ and $\hat{A}_2$ but related with the separate members of the EPR pair. Then,

$$|\Psi_n\rangle = \sum_{n_1,n_2} C_{n_1,n_2;n}|\psi_{n_1}\rangle|\phi_{n_2}\rangle, \tag{2}$$

where $C_{n_1,n_2;n}$ are the expansion coefficients, which determine a relative weight with which eigenstates $|\psi_{n_1}\rangle$ and $|\phi_{n_2}\rangle$ contribute to the total state vector.

The coefficients $C_{n_1,n_2;n}$, linking together three quantum numbers n_1, n_2 and n, i.e., determining some correlations between them, are associated with the conservation laws specific for these quantum numbers.

If the quantum state of a combined system $|\Psi_n\rangle$ can decay to the states of subsystems 1 and 2, then the total state vector $|\Psi_n^{(12)}\rangle$ of the quantum system, consisting on two independent subsystems, is written as

$$|\Psi_n^{(12)}\rangle = \mathcal{A}\sum_{n_1,n_2} C_{n_1,n_2;n}|\psi_{n_1}\rangle|\phi_{n_2}\rangle, \tag{3}$$

where $\mathcal{A}$ is the decaying amplitude of the state $|\Psi_n\rangle$, which determines the rate of corresponding decay channel, i.e., the rate by which the subsystems 1 and 2 are created.

The next imperfection regards the interpretation of the entangled state Eqs. (1). According to EPR, we have the subsystems 1 and 2, described by Eqs. (1), *before the measurement*.

But it is not so. Since the state (3) has dynamical origin, it is impossible to predict a decay moment onto the EPR pair. Therefore, one can not suppose that before the measurement we have two subsystems 1 and 2 described by the entangled state (3). Only after the measurement, in generally, of all subsystems one can say that the decay act took place.

The last objection is related with the understanding of the EPR pair measurement process. It is incorrect to imagine that the measurement of the first subsystem unambiguously predicts the result of the measurement of the second subsystem. Such picturesque exposition arises if one applies to the analysis of a quantum phenomenon the classical-type representations, which allow one to imagine a mechanical separation of the state vector $|\Psi\rangle$ into the parts corresponding to two subsystems.

But, it has nothing common with the quantum theory approach, which predicts the result of a single measurement performed on both members of the EPR pair (it doesn't matter, simultaneously or not, but in coincidence to be sure that both members have common origin). In a word, every prediction of quantum theory presupposes the state vector $|\Psi\rangle$ projection onto the pair of subsystems vectors, having characteristics of the corresponding measurement devices.

For example, the simplest observable when one measures a quantum process, is its intensity - the rate by which detectors register the final products. This rate is proportional to the probability to find two subsystems in the state $|\Psi_n^{(12)}\rangle$

$$p^{(12)} = ||\Psi_n^{(12)}\rangle|^2 = |\mathcal{A}|^2 \tag{4}$$

(assuming that $\sum_{n_1,n_2}|C_{n_1,n_2;n}|^2 = 1$).

The probability to find the subsystem 1 in the state $|\psi_{k_1}\rangle$ and the subsystem 2 in the state $|\phi_{k_2}\rangle$ is determined by the $|\Psi_n^{(12)}\rangle$ projection onto the product $|\psi_{k_1}\rangle \cdot |\phi_{k_2}\rangle$

$$p_{k_1,k_2}^{(12)} = |\langle\phi_{k_2}|\langle\psi_{k_1}|\Psi_n^{(12)}\rangle|^2 = |\mathcal{A}|^2|C_{k_1,k_2;n}|^2. \tag{5}$$

Again, this projection presupposes the measurements of both subsystems 1 and 2, which is in contradiction with the claim that the measurement of one subsystem unambiguously predicts the result of the measurement of other subsystem. Quantum-mechanical formalism doesn't sustain such a verbal expression type.

If one measures only, say, the subsystem 1, then the probability to find it in the state $|\psi_{k_1}\rangle$ is equal to

$$p_{k_1,\cdot}^{(12)} = \sum_{k_2}|\langle\phi_{k_2}|\langle\psi_{k_1}|\Psi_n^{(12)}\rangle|^2 = |\mathcal{A}|^2\sum_{k_2}|C_{k_1,k_2;n}|^2. \tag{6}$$

Summation over k_2 in this expression presupposes, in principle, the measurement of the second subsystem too, at least by its just registration.

In case the unstable system has a single decaying mode and quantum numbers k_1, k_2 entering in the decomposition coefficients $C_{k_1,k_2;n}$ are unambiguously correlated, measurements concerning the predictions (4) - (6) can be reduced to measurements performed on a single subsystem.

One can see that in such approach there is no any *spooky action at a distance.*