# The nature of Reality: Einstein-Podolsky-Rosen Argument in QM

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## Abstract

From conceptual point of view, we argue about the nature of reality inferred from EPR argument in quantum mechanics.

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## The Reality of EPR argument in Quantum Mechanics.

The Einsteinian research programme can be summarized in the following way:

> Physical theories are attempts at saying how things are. The world is comprehensible.

The above statement is a very general one, indeed this statement seems to be not enough to characterize uniquely Einstein's programme. In fact, that statement is also perfectly adaptable to the Galilean, Cartesian, Newtonian, Leibnizian, Maxwellian and several other scientific programmes. According to Einstein, quantum objects are concrete entities existing in a space-time where causality holds. In the following statement the Einstein's thought is more precise:

> Physical theories (including QM) are attempts at saying how things are (including quantum objects). The objective world is comprehensible. By the simultaneous help of space-time and causal conceptual categories we can study this comprehensible world.

To make explicit Einstein's claims in favor of objectivity and independence of reality[1]. In this framework we need to insert the EPR argument. In EPR work they demonstrated an inconsistency between the premises that go under the name of *local realism* and the notion that QM is complete. EPR never regarded it as a paradox, but as an argument to prove the incompleteness of QM.

A passage in a letter from Einstein to Max Born, dated March 24, 1948, illuminates some of the key issues for Einstein that lie behind the EPR paradox and what is at issue for him in his commitment to separability:

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[1] Instead, Bohr's scientific research programme can be summarized in the following way: Classical theories are attempts at saying how things are. The objective classical world is comprehensible. By using both space-time and causal categories we can study the classical world, but not the quantum world. According to Bohr, quantum phenomena are not comprehensible in the same sense as classical phenomena. In classical physics, objects are spatial and temporal entities that are ruled by causal laws. In this way, classical phenomena are comprehensible according to causal laws (conservation laws) in space-time. Thus in a classical context, the conceptual categories of space-time and cause can be used together to study physical phenomena. However, according to Bohr the situation changes drastically when we are dealing with quantum phenomena. In microphysics, the categories of space-time and cause can be used only in a mutually exclusive manner, according to Bohr's complementarity principle. According Bohr, quantum theory must be interpreted, not as a description of nature itself, but merely as a tool for making predictions about observations appearing under conditions described by classical physics. In other words, although quantum phenomena cannot be described by simultaneous use of the space-time and causal concepts, the use of these and other classical physics concepts is unavoidable.

> I just want to explain what I mean when I say that we should try to hold on to physical reality [....] That which we conceive as existing ("actual") should somehow be localized in time and space. That is, the real in one patt of space, A, should (in theory) somehow "exist" independently of that which is thought of as real in another part of space, B [....] What is actually present in B should thus not depend upon the type of measurement carried out in the part of space, A; it should also be independent of whether or not, after all, a measurement is made in A [... .]

Einstein maintained a belief in separability[2]as the very condition for the possibility of objectivity. According Howard, (Howard, 2007) Einstein's belief in separability in terms of a literal externality relation, the spatial separation between observer and observed:

> Like so many realists before him, Einstein speaks of the real world which physics aim to describe as the real "external" world, and he does so in such a way as to suggest that the independence of the real, its not being dependent in any significant way on ourselves as observers-is grounded in this "externality." For most other realists this talk of "externality" is at best a suggestive metaphor. But for Einstein, it is no metaphor. "Externality" is a relation of spatial separation, and the separability principle, the principle of "the mutually independent existence of spatially distant things," asserts that any two systems separated by so much as an infinitesimal spatial interval always possess separate states. Once we realize that observer and observed are themselves just previously interacting physical systems, we see that their independence is grounded in the separability principle along with the independence of all other physical systems.

In this first part of thesis, will be analyzed the EPR argument in detail because it contains the primitive notion of local causality used in discussions of Bell's theorem and the notion of quantum non-separability (Cavalcanti, 2008).
The original EPR paradox was based on position and momentum observables. Bohm in 1951 extended the example of EPR to the case of discrete observables (the case of two spin-1/2 particles). That is the version that was used by Bell in deriving his famous inequalities. It has played a central role in our understanding of QE. Both the original argument of EPR and Bohm's version, however, rely on perfect

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[2] Bohr rejects the separability condition.For Bohr, the quantum postulate and the material embodiment of concepts are at the root of quantum nonseparability (what Bohr often refers to as the "individuality" of phenomena).

correlations. For EPR-entanglement, local realism can only be reconciled with QM if one accepts the existence of an underlying localized *hidden variable* (non-quantum) state. In few words, if one can accept *only quantum* states, then the **EPR** correlation implies nonlocal effects[3].

The EPR paper starts (see below quotation) with a distinction between reality and the concepts of a theory, followed by a critique of the operationalist position (the Copenhagen school).

> "Any serious consideration of a physical theory must take into account the distinction between the objective reality, which is independent of any theory, and the physical concepts with which the theory operates. These concepts are intended to correspond with the objective reality, and by means of these concepts we picture this reality to ourselves. In attempting to judge the success of a physical theory, we may ask ourselves two questions: (1) 'Is the theory correct?' and (2) 'Is the description given by the theory complete?' It is only in the case in which positive answers may be given to both of these questions, that the concepts of the theory may be said to be satisfactory. The correctness of the theory is judged by the degree of agreement between the conclusions of the theory and human experience.

EPR argue that we must distinguish those concepts from the reality they attempt to describe. One can see the physical constructs of the theory as mere calculational tools (operationalist position or FAPP). But according EPR the theory must

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[3] As we will see in details, in QM the term "nonlocality" refers to the failure of a certain relativity-theory-based locality assumption. This assumption is that no information about which experiment is freely chosen and performed in one spacetime region can be present in a second spacetime region unless a point traveling at the speed of light (or less) can reach some point in the second region from some point in the first. This assumption is valid in relativistic classical physics. Yet quantum theory permits the existence of certain experimental situations in which this information-based locality assumption fails. The simplest of the experiments pertinent to this issue involve two measurements performed in two spacetime regions that lie so far apart that nothing traveling at the speed of light or less can pass from either of these two regions to the other. We will see that Bell's work, based on EPR argument, refer only to performable actions and observable outcomes. Bell's work do not analyze any notions of "microscopic", "invisible", or other "hidden variables". The assumptions are expressed at the macroscopic level. These assumptions cannot be consistently reconciled with the predictions of QM. Bell (1971) and others (Clauser et al,1969) went on to consider, instead of deterministic local hidden-variable theories, rather probabilistic local hidden variable theories. But, as shown by Stapp (1978), and independently by Fine (1982), this change does not substantially change the situation, because the two detailed formulations are equivalent.

strive to furnish a complete picture of reality. The position advocated by Einstein, is that the existence of physical events is independent of observers or reference frames and that those events can be associated to points in a relativistic space-time. This framework makes explicit, as EPR desired, that events are among those things which are part of the objective reality[4], which is independent of any theory. EPR follow the previous considerations with a *necessary condition for completeness:*

> **EPR's** necessary condition for completeness: "Whatever the meaning assigned to the term *complete,* the following requirement for a complete theory seems to be a necessary one: *every element of the physical reality must have a counterpart in the physical theory.*".

After they they note that this condition only makes sense if one is able to decide what are the elements of the physical reality. Contrary to a common belief, they did not then attempt to *define* element of physical reality. Instead, they provide a *sufficient condition of reality*:

> **EPR's** sufficient condition for reality: "The elements of the physical reality cannot be determined by *a priori* philosophical considerations, but must be found by an appeal to results of experiments and measurements. A comprehensive definition of reality is, however, unnecessary for our purpose. We shall be satisfied with the following criterion, which we regard as reasonable. *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.*".

EPR follow the analysis and they explicit a criterion that can be "regarded not as a necessary, but merely as a sufficient, condition of reality". This is followed by a discussion that, in QM, if a system is in an eigenstate of an operator $A$ with eigenvalue $a$, by this criterion, there must be an element of physical reality corresponding to the physical quantity $A$. "On the other hand", they continue, if the state of the system is a superposition of eigenstates of $A$, "we can no longer speak of the physical quantity $A$ having a particular value". After a few more considerations, they state that "the usual conclusion from this in QM is that *when*

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[4] Regarding the objective reality, the quantum non-locality denies the philosophical thesis that reality can be fully understood; and it seems to rejects the philosophical principle of sufficient reason, which goes back to classical Greek philosophy and says that every event has a cause.

*the momentum of a particle is known, its coordinate has no physical reality*". We are left therefore, according to EPR, with two alternatives:

> **EPR's central dilemma:** "From this follows that either (1) *the quantum-mechanical description of reality given by the wave function is not complete or* (2) *when the operators corresponding to two physical quantities do not commute the two quantities cannot have simultaneous reality.*

They justify this by reasoning that "if both of them had simultaneous reality, and thus definite values,these values would enter into the complete description, according to the condition for completeness". And in the crucial step of the reasoning: "If then the wave function provided such a complete description of reality it would contain these values (i.e. these would then be predictable).

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