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COMMENTS ON "LOCALITY, BELL'S THEOREM, AND QUANTUM MECHANICS"

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Abstract

Two different ideas of locality are described. Both are due essentially to Einstein. Quantum theory is compatible with the first but not the second. The problems encountered in the article cited in the title arise from trying to use only the first idea of locality, whereas Bell's-theorem considerations pertain to the second.

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The questions raised in the cited article 1/ emphasize the importance of distinguishing between two different ideas of locality, both due essentially to Einstein. The first is the idea that no signal can travel faster than light. The second is the idea that the course of events in one spacetime region can be in no way disturbed by what is done in a spacetime region that is spatially separated from the first.

The first idea of locality was used by Einstein in the theory of relativity. The second was used by Einstein, Podolsky, and Rosen 2/ in their analysis of quantum theory. The problems encountered in the cited article arise from the attempt to use there only the first idea of locality, whereas Bell's-theorem considerations pertain to the second.

The idea that the course of events in one spacetime region can be in no way disturbed by what is done in a spatially separated region is an expression of the idea that influences travel no faster than light. The occurrence of the word "can" alludes to the presumed existence of laws of nature that relate the possibilities for what can happen under alternative possible conditions. In the situation analyzed by Einstein, Podolsky, and Rosen these relationships were supposed to ensure that no matter which experiment was performed in a spacetime region, and no matter what result appears there, that result, whatever it might be, must, in any case, be independent of which experiment is freely chosen and performed in a spacetime region that is spatially separated from the first.

The demand that these independence properties must hold is a strong locality condition. A much weaker condition for a theory or model to be local is that the predictions of the theory or model be at least compatible with the possibility that this strong locality condition could hold. Quantum theory is nonlocal in this second sense: it is incompatible with the theoretical possibility that, for each of the two conditions that might be set up in either region, the results that would appear under those conditions could be independent of which experiment is freely chosen and performed in the spatially separated region.

The argument in the cited article consists of two parts. First, a model is exhibited that conforms to the first idea of locality, in that it provides no possibility for faster-than-light signalling, but that violates a mathematical locality condition SL defined in that article. Then it is asked whether the model is nonlocal in some physical sense. The last three paragraphs of section three of the cited article, taken together, show that the model considered there is nonlocal in the second sense discussed above: the model, like quantum theory, excludes the possibility that what would appear in each region, under either of the conditions that might be set up there, could be independent of which experiment is freely chosen and performed in the spatially separated region. The model thus provides a simple concrete illustration of the distinction between the two kinds of locality.

Passing from the model to the general situation the two central questions raised, at least implicitly, in the cited article are:

1) Does locality of the second kind (i.e., EPR locality) entail the condition SL defined in the cited article? and

2) Does knowledge of the failure of EPR locality have any potential importance for the development of physics?

As regards question 1) it is essential that the derivation of SL from EPR locality involve no assumption that the results of unperformed experiments be well defined. For such an assumption would be tantamount to assuming hidden-variables, which would contravene the precepts of quantum theory.

Question 2) will be answered later. The potential importance will relate to our knowledge of the causal structure of the laws of nature, as these laws are reflected in our theories about nature. Thus, the issue concerns the allowed causal structures of physical theories.

To consider question 1) in a concrete way suppose the experimenter in each region will press one of two buttons to activate his choice between the two possible experiments in his region. Suppose that what appears is assumed to depend on the time in microseconds when the button is pressed, and that this time is indeterminate in the sense of quantum theory. Thus what would happen in an unperformed experiment is indeterminate: it is not determined. And what will happen is likewise undetermined.

One can nevertheless pose the question of whether the possibilities for what can appear could be limited by the laws of nature so that no matter which of the two alternative possible experiments is performed in one region, and no matter what result appears there, that result, whatever it might be, must, in any case, be independent of which experiment is performed in the far-away region. That is, one can pose the question of whether it is possible to limit the possibilities for what can appear by imposing Einstein's condition that the course of events in one region can be in no way disturbed by what is done in the other region.

If we consider, then, two possibilities, a and b, for the experiment to be performed in region V, and two possibilities, c and d, for the experiment to be performed in region W, then the Einstein condition of nondisturbance requires that if result A would appear in V under conditions (a,c) then this same result A, whatever it might be, would appear in V also under conditions (a,d).

Likewise, if result B would appear in V under conditions (b,c) then this same result B would appear in V also under conditions (b,d). Similarly, if result C would appear in W under conditions (a,c), then this same result C would appear in W also under conditions (b,c). Finally, if result D would appear in W under conditions (a,d) then this same result D would appear also under conditions (b,d). Thus the condition of nondisturbance reduces the possibilities for what can appear under the four alternative possible conditions from a set with eight degrees of freedom to a set with only four degrees of freedom, and one obtains condition SL.

The potential importance for physics of distinguishing between the two kinds of locality, and recognizing that locality of the second kind, i.e., EPR locality, is incompatible with the predictions of quantum theory lies in the freedom this knowledge provides in the construction of physical theories. Present-day quantum theory is limited in scope by its inherently different modes of descriptions of atomic systems and the environments of which they are a part. This dualistic description entails that there is no precise way to treat quantum systems that are so large that they significantly influence their classically described environment. A unified description is apparently needed, and in the construction of this unified description the question of the possible forms of causal connection must inevitably arise.

For example, Heisenberg 4/ tried in 1958 to interpret the wave function of quantum theory in an objective fashion in terms of objective potentia for objective events, but was turned back to an interpretation in terms of knowledge of observers apparently, at least in part, by the nonlocal character of his objective interpretation. But the nonlocal effects he encountered were not of the kind that would allow sending signals faster than light. So his attempt at a unified objective interpretation was blocked by a certain conception of locality requirements that can now be seen as unnecessarily restrictive. The importance of distinguishing the two notions of locality, and recognizing the inapplicability of the second one in the domain of quantum phenomena, is thus that it releases from the limitations imposed by an overly restrictive idea of locality the process of constructing physical theories of greater scope. More incisively, the development of an adequate integral theory of quantum and classical phenomena may depend critically on recognizing that in any such theory EPR locality must necessarily fail. These matters are discussed in more detail in the second ref. 3.

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