Title: Nonlocality and Bohr's Reply to EPR

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ABSTRACT

David Mermin's recent paper with the same title as this one makes it clear that his claim to have found a gap in my reasoning rests on his claim that my argument violates a criterion for meaningfulness of counterfactual statements that I myself had set down. I set down no such requirement. But I am willing to accept it as a conservative sufficient condition. This already entails, within my proof, that nature must have a deep structure that extends beyond what actually occurs. It imposes, without appeal to the notion of determinism or hidden variables, constraints connecting, at the macroscopic level, what did occur to what would have occurred if certain quantum choices had gone differently. All the statements in the proof have natural meanings within the context of an examination of that deep structure.

Mermin correctly points out that Bohr did not use the term "action-at-a-distance" in connection with the influence that was under discussion in his exchange with EPR. Nor did the latter authors. But Einstein later spoke of "spooky action-at-a-distance" and identified it as the key point when he said[8] "One can escape from this [EPR] conclusion only by either assuming that the measurement of S_1 ((telepathically)) changes the real situation of S_2 or by denying independent real situations as such to things that are spatially separated from each other." Bohr himself translated the mathematical EPR argument into a physical procedure that involved "a rigid diaphragm with two parallel slits, which are very narrow compared with their separation, and through each of which one particle with given momentum passes independently of the other." An experimenter subsequently can measure either the momentum or the position of one of the two particle, and the point of Bohr's argument was to show that this measurement of one particle *does*, within his knowledge-based, prediction-oriented framework, influence the other particle, thereby upsetting the condition "without in any way disturbing the system", which EPR require in order to apply their criterion of physical reality.

Mermin's claim to have found an error in my argument hinges on his claim that I set down conditions under which counterfactuals can be used. But I set down no such conditions. I argued against the wholesale exclusion of counterfactual argumentation by giving some simple examples. Mermin misread me if he thought I was requiring all counterfactuals to be of that simplest kind. Rather I adhered throughout to the rules [modal logic] that philosophers have developed for specifying the meanings of counterfactual conditions.

Thus Mermin should not claim that there was an error in my reasoning: that I violated precepts that I myself had set forth. Rather, if he wants to limit the meaningfulness of counterfactual statements then he should show why the normal rules of counterfactual reasoning [as developed by philosophers who deal with this problem] must be augmented in a way that makes my proof invalid.

Mermin's central claim is that my statement

(S): If R2 was performed and gave +, then performing R1, instead, would have given −.

is neither true nor false, if L1 is performed, but meaningless. Mermin's argument for this is that: "I am merely noting that the statement fails to meet the rule for when a counterfactual makes sense." Later he says "The essential ambiguity responsible for the gap in Stapp's argument lies not in LOC2 but in the statement (S) to which Stapp wishes to apply LOC2. The counterfactual part of (S), which apparently refers only to past events (which is essential for the applicability of LOC2) actually makes implicit reference to future events, through the criterion for the validity of a counterfactual statement. This implicit future reference does not make LOC2 *fail*: it renders LOC2 *inapplicable.*

Mermin refers "the rule" or "the criterion" for the meaningfulness or validity of a counterfactual statement. The rule he proposes was taken from my discussion of a simple example. I will accept this criterion as a conservative *sufficient condition* for meaningfulness. This is useful because it leads, as Mermin points out, to the meaningfulness of (S) under condition L2. This is important because quantum physicists are prone to the easy view that only the actually performed experiment has any significance, and hence *all* counterfactual argumentation is meaningless. That view would make the entire Bohr-EPR exchange meaningless, because the entire discussion is about the effect of changing a free choice made in one place upon physical reality elsewhere, and this notion is formulated in terms of counterfactuals. Bohr did not challenge EPR on the basis of the meaninglessness of counterfactuals in science. Rather he affirmed that one could regard the choices made by the experimenters as "free", and could talk in the normal way about such things *at the level of experimental procedures and observable possible results.* He took the tack of redefining the meaning of "physical reality". Thus Mermin's challenge to my argument is basically dissimiliar to Bohr's challenge to EPR.

The importance of the conservative Stapp-Mermin criterion is that it provide a toe-hold. By validating (S) under condition L2 it establishes that there is something to talk about. For it establishes that Nature has some deep structure that goes beyond what actually happens: it says that, under the condition that L2 is performed later, there is in Nature some connection of what actually happens in the earlier region to *what would have happened* there if the experimenter there had made the opposite choice. This derived property *would have happened* is not based on any assumption of determinism: it comes out of the predictions of quantum theory itself, in conjunction with the locality condition LOC1.

Having established under the conservative criterion that Nature has a deep structure that extends beyond the bounds of the single actually occurring situation, and relates actual happenings to what would have happened if... we have made the big leap. In exploring further this deep structure we must make sure that our words are not just verbal formulas: they are supposed to be describing various other aspects of this deep structure of nature. Without that connection of our words to the now-establihed deep structure the whole project would collapse.

Philosophers have worked out rules [modal logic] for dealing with this situation: these rules allow our use of words to conform correctly to the natural meaning normally ascribed to those words. I adhere to those rules, which are completely appropriate to the situation under consideration here, where our purpose is to explore properties of nature that involve connections among alternative possibilities that we are free to create.

Statement (S) has a natural meaning that is captured in modal logic. This condition is formulated within a theoretical context of pairs of possible worlds that are almost the same, but that differ in some specified way at some first time where there is a significant difference. The theoretical contemplation of such slightly differing pairs is even more reasonable in a nondeterministic quantum context than in a deterministic classical context, since within the former context one should be able to contemplate two possible worlds that are the same at some time except that in one the decay of a radioactive nucleus has just been detected, and this detection will cause the second experiment to be performed, whereas in the other possible world this decay has not been detected, and the first experiment will consequently be performed.

The meaning of (S) closely parallels the meaning of an ordinary statement "If under condition A result x appears, then under condition B result y appears". The essential difference is that the extra word "instead" in (S) breaks the usual rule that truth of the first condition (R2) allows one to conclude that the contradictory premise (R1) of the subordinate clause is false. This change allows one to relate the possibilities for the outcome of the two alterative possible experiments in the way specified by the sentence.

This "meaning" of statement (S) is strictly in terms of a relationship between the possibilities for the outcomes of alternative possible experiments both of which are confined to the region R. This asserted connection between the possibilities for the outcomes of the two alternative possible experiments may, by virtue of the deep structure of nature, be true or false under various possible conditions, but they do not automatically become "meaningless" if not directly provable in some simplest way.

Given this natural meaning, the statement (S) could conceivably remain true if L1 is performed instead of L2. LOC2 is just the assertion that (S) does remain true under this substitution. This property is plausible because the free choice between L1 and L2 does not occur until after everything referred to in (S) has already either happened or not happened: so it is hard to see how the truth of (S) could depend on the later free choice without there being some backward-in-time influence.

Mermin claims that the criterion for meaningfulness, regarded now as a necessary condition, shows that LOC2 cannot be applied because the "meaning" of (S) "implicitly" involves events in L. In my earlier reply I countered his argument by ascribing the natural meaning to (S) [i.e., the meaning in terms of constraints on possibilities of outcomes] simply as a matter of definition, which I am entitled to do, and in fact am obliged to do because this is the strict meaning by virtue of which (S) is proved to be true under condition L2. Then I defined LOC2 as simply asserting that (S) held true also under condition L1. Then is there no question about the "applicability" of this condition of LOC2: it is nothing more than the /it assertion that the deep structure of nature is such as to make that connection between possibilities of outcomes that is directly described by (S) continue to hold if the later free choice is to perform L1 instead of L2.

Once it has been established that the deep structure in nature exists, then one should adhere consistently to the natural meaning of (S) as a description of a possible consequence of that structure, rather than sometimes branding (S) as meaningless when, as a description of a possible consequence of this deep structure that is under investigation, it has a natural meaning.

Ref. 8 A. Einstein, in Albert Einstein: Philosopher-Scientist, ed. P.A. Schilpp Tudor, NY, !951 p.85