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Comments on Shimony's "An Analysis of Stapp's 'A bell-type theorem without hidden variables' "

Henry P. Stapp*

Lawrence Berkeley National Laboratory

University of California

Berkeley, California 94720.

ABSTRACT

The hidden-variable theorems of Bell and followers depend upon an assumption, namely the hidden-variable assumption, that conflicts with the precepts of quantum philosophy. Hence from an orthodox quantum perspective those theorems entail no faster-than-light transfer of information. They merely reinforce the ban on hidden variables. The need for some sort of faster-than-light information transfer can be shown by using counterfactuals instead of hidden variables. Shimony's criticism of that argument fails to take into account the distinction between no-faster-than-light connection in one direction and that same condition in both directions. The argument can be cleanly formulated within the framework of a fixed past, open future interpretation of quantum theory, which neatly accommodates the critical assumptions that the experimenters are free to choose which experiments they will perform. The assumptions are compatible with the Tomonaga-Schwinger formulation of quantum field theory, and hence with orthodox quantum precepts, and with the relativistic requirement that no prediction pertaining to an outcome in one region can depend upon a free choice made in a region spacelike-separated from the first.

Bell's theorem, Nonlocality, Hidden variables, Counterfactuals

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Asher Peres has had a long-standing interest in the subject matter of this article, and I have benefited for numerous communications with him on this topic. The form of this paper is in part a consequence of his insightful demands for mathematical rigor combined with conceptual clarity in the approach to fundamental issues.

1. NEED TO IMPROVE BELL'S NO-LOCAL-HIDDEN-VARIABLE THEOREMS

Professor Shimony's article[1] is an extremely helpful contribution to the subject. It summarizes in a lucid way the large areas of agreement between us, and provides a back-to-basics proof of the two propositions that are the main technical results of my paper[2]. Shimony's long and detailed derivation of those two basic propositions should lay completely to rest all but one of the objections that were raised against my more compact 1997 proof[3]. I shall examine presently that remaining objection, but first will emphasize some key points of agreement mentioned by Shimony.

Shimony identifies the motivation of my work, namely the fact that the theorems of J.S. Bell[4] and his followers[5] rest explicitly or implicitly on the local-hidden-variable assumption that the values of the pertinent observables exist whether they are measured or not. That assumption conflicts with orthodox quantum philosophy, and that fact undermines the idea that some sort of faster-than-light transfer of information is implied by the conjunction of Bell's theorem and the assumed validity of the predictions of quantum theory. The more likely conclusion, from the orthodox perspective, is a failure of the hidden-variable assumption. The orthodox interpretation of Bell's theorem is not that faster-than-light transfer of information exists. It is rather that the hidden-variable assumption is false. Shimony notes that a proof not requiring a hidden-variable assumption of the need in quantum theory for faster-than-light information transfer "would be a profound scientific and philosophical achievement."

2. SHIMONY'S OBJECTION AND THE FIXED PAST, OPEN FUTURE APPROACH

Shimony questions the sufficiency of my reasons for supplementing my 1997 proof with the 2004 version[2]. He examines, consequently, not my new proof but rather the explicitly counterfactual approach that I proposed in a published reply to his earlier comments. That approach differs fundamentally from the one used in my 2004 paper, but his proof of the validity of the two propositions covers both formulations.

The proof constructed and criticized by Shimony lies within the general framework of counterfactual reasoning, whereas my 2004 proof, although retaining some of the trappings and language of counterfactual argumentation, is based on a substantially different foundation. The combination of my assumptions of “free choices” and of “no backward-in-time influence” amounts to the assumption that theories covered by my new work *are to be compatible with* the idea of “*fixed past, open future*”. This conceptualization circumvents, at the foundational level, the need for counterfactuals. It accords with the notion of an advancing “now” in which events occur that “fix and settle” first the free choice made by any agent about which experiment he will perform, and later the outcome of that freely chosen experiment. The future is “open” in the sense that the choices in regions R and L of which experiments are to be performed in those regions are required to be treatable, within the theory, as free choices that are made by the agents when the moment ”now” arrives. The subsequent “choice of the outcome of the freely chosen experiment” is likewise required to be treatable, within the class of theories to which the propositions apply, as undetermined until the advancing moment "now" arrives, at which time the outcome also becomes "fixed and settled". These latter choices are termed "nature's choices" and are required to conform to the statistical rules of quantum theory. Treating the theory in this way is supposed to be one adequate way of expressing the content of the theory, although perhaps not the only possible way.

This switch from an approach formulated in the framework of "counterfactuals" to one formulated in the framework of "fixed past, open future" has no significant effect on the proofs of the two propositions. But it brings the concepts being used into closer accord with those of orthodox quantum thinking. Although philosophers contend that counterfactual concepts pervade science, and are needed for science, the significance of results based on the use of counterfactuals remains somewhat shakey in the minds of most quantum physicists. But the idea that the events already observed in the past by somebody can be treated as if they are fixed and settled, and that our future choices can be treated as if they free, agrees with the way that physicists deal with their theories, with their theoretical practices, and with their lives in general.

Shimony's objection to my argument begins with the assertion "But SR is not an assertion about actually occurring events. It is a counterfactual conditional “. This statement alone activates the intuitive distrust of scientists in arguments based on counterfactuals. I shall deal presently with Shimony’s specific objection, raised within the framework of the counterfactual formulation. But first I shall describe the application of the two propositions from the “fixed past, open future” point of view that is more congenial with the normal thinking of physicists.

Why does Shimony claim that the validity of these two propositions lacks scientific significance?

This wording is not exactly the way that Shimony put it. But scientific significance is the basic issue. The theorems of Bell and his followers are ultimately of value because they rule out certain possible models or theories of nature. The pertinent questions are thus: Does the joint validity of the two propositions rule out some models or theories of nature that are not ruled out by Bell’s theorems? And does the joint validity of these two propositions rule out all of the local-hidden variable theories that are eliminated by Bell’s theorem? If the joint validity of these two propositions does indeed rule out all of the hidden-variable theories covered by Bell’s theorem, and others besides, then these propositions are jointly stronger than Bell’s Theorem, both because their consequences are stronger—they rule out more theories---and also because their assumptions are weaker. In this connection it is important to notice that it is not *nature* that is required to conform to the assumptions. It is rather that a *theory* must, in order for these propositions to be applicable to that theory, be such that the choice made by the experimenter in the later region R *can be treated* as a free variable, effectively undetermined until the moment of the decision, and that whatever outcome has already been observed in the earlier region L *can be considered* to remain undisturbed by the subsequent events. The premises of the two propositions are thus *conditions on the class of theories* to which these propositions apply.

To see how this works, suppose you are trying to construct a local theory that agrees with the predictions of Quantum Theory. Then what has been proved is that if this theory is merely such that (1) the experimenter's choices can be considered "free" (i.e., without any *relevant* causal roots), and (2) what is observed to happen in region L can be considered to be fixed and settled independently of whether R1 or R2 will later be freely chosen and performed by the experimenter in region R, and (3) the predictions of quantum theory for the Hardy experiments are valid, then the theory must, for these experiments, satisfy the following two properties:

I. If L2 is performed in L, then if R2 were to be performed and were to give outcome + then if R1 were to be performed, the outcome would always be --.

II If L1 is performed in L, then if R2 were to be performed and were to give outcome + then if R1 were to be performed the outcome would sometimes be +.

I have eliminated here the counterfactual terminology that was employed in my counterfactual-based 1997 paper, and that was retained in my 2004 paper for the sake of historical continuity. I have adopted here the language appropriate to the assumptions of my 2004 paper, which, as emphasized above, are concordant with the idea of fixed past open future. The two propositions pertain to the *structure of a theory* in which the free variables are the open choices to be made by the experimenters as to which experiments will be performed, and the two propositions are assertions pertaining to relationships that then follow from the combination of the assumption of the validity of the relevant predictions of quantum theory, together with the idea that the outcomes that have already been observed by some human witness in one region can be treated as fixed and settled, completely unalterable by subsequent free choices made in a region space-like separated from the first.

Although something akin to hidden variables might be *entailed* by these propositions, any such structure is here a *consequence* of our fixed past, open future assumptions, together with the assumptions of the predictions of QM. These *consequences* are *not* hidden-variable *assumptions*.

These two propositions, taken together, entail the presence in region R of information about the free choice made in L between L1 and L2:
no theory that satisfies these to propositions can be “local” in the sense that it is logically compatible with an exclusion of all faster-than-light transfers of information.

No *local-hidden-variable theory* can satisfy both of these properties: In such a theory the observable properties are fixed and definite whether they are measured of not, and they do not depend upon which experiment is chosen and performed far away. That combination of conditions is not compatible with the validity of these two propositions.

No Bell-type hidden-variable *assumption* has entered into the proof of the two properties. These two propositions are consequences simply of the assumptions that the theory is compatible with the theoretical concept of “fixed past, open future”, in conjunction with the validity of predictions of quantum theory for this Hardy-type experiment.

Relativistic quantum field theory (RQFT) is compatible with the premises of the propositions. This is shown by the works of Tomonaga[6] and Schwinger[7] (T&S), where an advancing surface “now” is a parameterized space-like surface $\sigma(\tau)$ such that for $\tau' \leq \tau$ the surface $\sigma(\tau')$ lies nowhere later than $\sigma(\tau)$, but is somewhere earlier. In the T&S formulation there exists a fixed history of the evolution of the state vector $\Psi(\sigma(\tau))$ for all $\sigma(\tau')$ up until the present time "Now". In that formulation there is also, in association with the fixing of any outcome, a change of the state vector $\psi(\sigma(\tau))$ that produces an instantaneous transfer of information along the space-like surfaces $\sigma(\tau)$. But in spite of the existence within the T&S formulation of RQFT of this instantaneous information transfer along space-like surfaces, all the predictions of the theory about outcomes of measurements conform to the requirement of relativity theory that no such prediction pertaining to an experiment performed in one space-time region can depend upon which experiment is chosen and performed in a second space-time region that is situated space-like relative to the first.

The fact that the T&S formulation of RQFT does involve faster-than-light information transfers does not by itself entail that the existence of such transfers is an intrinsic feature of RQFT itself. There are other formulations that focus directly on connections between observables, and in which no trace of faster-than-light information transfer is evident. However, application of the two propositions requires merely that theory under examination be "compatible with" the concepts of "fixed past, open future", in the sense that, without altering the content of the theory, the choice between R1 and R2 *can be treated* as free, and the outcome of the earlier observation in L *can be treated* as fixed and settled prior to the fixing of the later choice in R The validity of this assumption is entailed by the T&S formulation of RQFT, and hence RQFT itself is *covered* by arguments based on the propositions..

The general conclusion is that *no theory* that can be treated in accordance with the idea of fixed past, open future, and that accords with the quantum predictions for the Hardy experiments, can be reconciled with a locality requirement that bans all faster-than-light transfer of information.

3. AN ILLUSTRATION

To illustrate the argument let us consider a complex model. Suppose in region R there is a genie who receives the particle, and extracts information from it, which he then combines with some random numbers, and with the information about which experiment, R1 or R2, is being performed in R, and then issues the output information in accordance with some unstated rules, which, however, lead to results concordant with the predictions of quantum theory. Without making any further assumption about what the rules are, beyond the assertion that the free choice between R1 and R2 made in R cannot disturb what has already become fixed and settled in L, we know that if the experimenter in L chooses to perform L2 then the genie's rules, whatever they are, must entail a special connection between the outcomes that he would issue in the two alternative cases R1 or R2.: If, in some instance, the agent in R were to choose R2 and the genie were to choose +

then if in that instance the agent were to choose R1, the genie must definitely issues the outcome – . On the other hand, that same rule cannot always be obeyed if the experimenter in L chooses L1. But this difference means that information about whether L1 or L2 was chosen in L must be present in R: the genie located in R cannot issue outcomes that depend upon the choice between L1 and L2 made by the experimenter in L if no information about that free choice in L is available in R.

If no information about the free choice between L1 and L2 can get to R, then this genie-model is ruled out. But it is not ruled out by Bell's theorem: Bell's hidden-variable assumptions are stronger than those of the genie-model. Indeed, if one simply replaces the genie with "a localized process" then the assumptions of that model are compatible not only with quantum philosophy, but with relativistic quantum field theory itself. Thus my results yield conclusions that are not entailed by the theorems of Bell and his followers. They express in the form of a pair of specific propositions an important feature of all theories that seek to go beyond the mere expression of correlations between observations: they must reject either the idea that our choices can be treated as free, or the notion that there is no faster-than-light (including backward in time) transfer of information, if they are to give the quantum predictions for the Hardy-type experiments

4. SHIMONY'S OBJECTION

We now turn to the two key questions:

1. Does Shimony's argument reveal any flaw in this fixed-past-open-future argument?
2. Does Shimony's argument reveal any flaw in the corresponding counterfactual-based argument?

I shall argue that the answer to both questions is No!

Shimony asserts that "The error in Stapp's argument is his claim that SR is a statement about region R alone", But what I actually said, as he correctly recorded, was that "the truth or falsity of SR is defined by conditions on the truth or falsity of statements describing possible events located in region R". This difference in wording is significant. My argument, given above, is based on *my* wording: I displayed two propositions that both follow from the stated assumptions, but that are---because of the fact that their truth or falsity is defined by conditions on the truth or falsity of statements describing events located in R--jointly incompatible with a ban on transfer of information to R of the choice between L1 and L2 made by the experimenter in region L. Shimony treats the entire statement SR, which involves counterfactuals, as a unit that incorporates, *within itself*, my key assumption that what happened in L was fixed and settled before the decision between R1 and R2 was made, whereas I take this key assumption to be a restriction on the class of theories within which the pair of propositions is proved to be true.

This latter approach of taking the stated assumptions to be conditions on the class of theories in which the two propositions are jointly true is a direct and completely legitimate way to proceed. Incorporating the key assumption of no-backward-in-time influence into the meaning of a counterfactual statement is less satisfactory for two reasons. In the first place the mere use of statements about events that in principle can never happen, because some contrary thing has been asserted to have definitely happened tends by itself to render the argument less than ideally rock solid in the minds of physicists. On the other hand, speaking directly about properties of a class of theories that satisfy certain specified conditions that are themselves in line with quantum philosophy, and are actually satisfied by relativistic quantum field theory, is a far more transparent approach that is less likely to enshroud subtle difficulties. The second reason is the closely connected fact that the scrambling the key causality assumption into the meaning of the words that express contrary-to-fact assertions opens the door to possible confusion.

The essential point here is that one must be careful not to introduce any assumption that injects implicitly into the theory the transfer of information from L to R that the joint validity of the two propositions reveals to be present. Shimony's criticism possesses a certain initial aura of credibility due to the fact that introducing *any* causal connection between events in R and in L *harbors the danger* of injecting implicitly some hidden assumption of the very influence from L to R that the argument eventually reveals. If a hidden assumption of an influence from R to L is smuggled into the assumptions then the fact that such a connection eventually emerges would lack significance.. On the other hand, if no such assumption is smuggled in, and the conclusion that there must be transfer of information from L to R follows logically from completely legitimate assumptions, including, in an essential way, the pertinent predictions of quantum theory, then the conclusion pertaining to the theories in question must be deemed to be logically valid.

It is well-know that quantum theory is completely compatible with the absence of faster-than-light influences in one direction, provided such influences are allowed in other directions. The question at issue is whether one can simultaneously forbid faster-than-light influences in all directions. Hence if we wish to prove the need for faster-than-light influence in *some* direction then we can legitimately proceed by *excluding* faster-than-light action in one direction, say right to left, and then showing that this restriction entails, when combined with the assumption of the validity of pertinent predictions of quantum theory, the need for faster-than-light transfer of information in the other direction, namely from left to right. This is the completely legitimate line of argument that I employ.

The first part of this legitimate argument is implemented by my assumption that the earlier observed outcome in L is fixed and settled, independently of what the later free choice in R will be. This assumption of not a hidden assumption of the existence of an action from left to right. It is the completely legitimate-in-this-context demand that there be no action from right to left. This assumption, by itself, does not entail any influence from left to right. Only when combined with the predictions of quantum theory does it lead to the conclusion that there must be information transfer from left to right. Thus the requirement of no action from right to left, whether regarded as a condition on the class of covered theories, or as part of the meaning of SR, is completely legitimate, in the context of this proof. But Shimony's analysis does not distinguish this completely-legitimate-in-this-context assumption of no action from right to left from what would be a completely illegitimate assumption of action from left to right.

The logical structure of the proof---with the two very different statuses of (1) the input assumption of no action from right to left and (2) the resulting output conclusion of a necessary transfer of information from left to right ---is revealed far more clearly and directly in the fixed-past-open-future formulation of the conditions for applicability of two propositions than in an approach that mixes counterfactual concepts into the meanings of the words appearing in the proofs. If that latter approach is used, then it is necessary in principle to unpack the counterfactual statements in order to clearly distinguish between legitimate inputs and possible illegitimate ones. Shimony's counterfactual-based analysis fails make this crucial distinction. In lieu of making this distinction within the counterfactual approach, the alternative and simpler way to verify the validity of the basic claim is to work directly from the assumptions of my 2004 paper, in the way described above, and thereby circumvent the complexities introduced by the avoidable use of counterfactuals.

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