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Comment on Unruh's Paper *

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Abstract

William Unruh has commented on my recent proof of the incompatibility of certain predictions of quantum theory with the idea that no influence of any kind can act backward in time in any Lorentz frame. He argues that my proof contains, contrary to my explicit claim, a tacit reality assumption that conflicts with the ideas of quantum theory, However, Unruh's argument fails to draw a necessary distinction between statements that make assertions that certain actual values exist and statements that make assertions that certain correlations between possible values exist. As a consequence his argument fails to establish the claimed result.

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Disclaimer

Unruh's essential point[1] in expressed in his two consecutive paragraphs that read as follows:

"However, great care is required in such counter-factual statements that one does not import into the statements a notion of reality. In particular, the truth of the statement made about system A which relies on measurement made on system B and on the correlations which have been established between A and B in the state of the joint system is entirely dependent on the truth of the actual measurement which has been made on system B. To divorce them is to effectively claim that the statement made about A can have a value in and of itself, and independent of measurements which have been made on A. This notion is equivalent to asserting the reality of the statement about A independent of measurements, a position contradicted by quantum mechanics.

"Thus in the above system, measuring σ_z on particle one can lead to one assigning a value + to σ_x of particle 2, even if that attribute was not measured, due to the correlation between the two particles. However, that value for σ_{2x} is entirely dependent upon the fact that σ_x was actually measured on particle 1. In particular, causality cannot be used to argue that the inferred fact of the value of σ_{2x} must be independent of what was measured at particle 1. Such an extension of the concept of locality is inapplicable to a quantum system, and is certainly not necessary to capture the concept of locality."

The first paragraph already contains some linguistic irregularities that are harbingers of trouble ahead. In order to be relevant to the case at hand [see below] one should take "relies on measurement made on system B" to mean "relies upon the fact that a certain specified measurement is made on system B". And "the truth of the actual measurement which has been made on system B" should mean "truth of the statement that the specified measurement has been made on system B." Also, "the statement made about A can have a value in and of itself," should mean "the statement made about A can have a truth value in and of itself." And the "reality of the statement about A" should be "the truth of the statement about A".

The linguistic irregularities in Unruh's original wording appear to stem from an effort to make one wording cover two very different situations. The first case is the familiar one in which certain outcomes, hence *values*, in the two different systems are correlated, so that the *value* obtained in one region fixes the *value* that would be found in the other system if the appropriate measurement were actually performed there. The second case is the one that occurs in my proof. There the *truth of a statement about correlations between possible outcomes in one system* is dependent solely upon *which measurement is performed* on a faraway system at a later time. Unruh's argument involves confounding these two very different cases.

In the first case the regular wording of the paragraph would be this:

"However, great care is required in such counter-factual statements that one does not import into the statements a notion of reality. In particular, the truth of the statement made about *a value in* A which relies on *a value obtained from a* measurement made on system B and on the correlations which have been established between *values in* A and B in the state of the joint system is entirely dependent on the fact that the actual measurement has been made on system B. To divorce them is to effectively claim that A can have *a value* in and of itself, and independent of measurements which have been made on A. This notion is equivalent to asserting the reality of the *value in* A independent of measurements, a position contradicted by quantum mechanics."

This is the normal sort of quantum reasoning.

But to make the statement cover the relevant step in my proof the statement should read:

"However, great care is required in such counter-factual statements that one does not import into the statements a notion of reality. In particular, the truth of the statement made about *correlations in* system A which relies upon the fact that a certain specified measurement is made on system B, and on the correlations which have been established between A and B in the state of the joint system is entirely dependent on the truth of the statement that the specified measurement has been made on system B. To divorce them is to effectively claim that the statement made about *correlations in* A can have a truth value in and of itself, and independent of measurements which have been made on A. This notion is equivalent to asserting the truth of the statement about A independent of measurements, a position contradicted by quantum mechanics."

Now everything again fits together linguistically, and fits the context of my proof. But the truth of the final assertion “a position contradicted by quantum mechanics” is not so obvious: why cannot the truth of a statement about A be independent of which measurement is performed faraway on system B at a later time, when the statement in question merely asserts the existence of a certain *correlation* between the outcomes of possible measurements in A, not the existence of any actual *values* in A.

Indeed, the theory of relativity suggests that the truth of such a statement about system A should not depend upon which measurement on the faraway system B is freely chosen at the later time.

Let us examine the matter more closely.

The step in my argument that is under attack here is the step from Line 5 to Line 6. Line 5 has been proved by using three assumptions: 1) the choices made by the experimenters can be treated as free (unconstrained) variables; 2) a locality assumption LOC1 that expresses the idea that the macroscopic outcomes that appear in one region are independent of what a faraway experimenter chooses to do at some later time; and 3) the assumption that if any of the experiments under consideration here is performed then nature will produce an outcome that is in accord with the predictions of quantum theory.

The result stated in Line 5 is not being challenged. It reads:

Line 5: “If L2 is performed then statement SR is true.”

Here SR is the statement:

SR: “If R2 is performed in region R, and the outcome there is +, then if R1, instead of R2, had been performed in region R, the outcome there would have been –.”

The region L is supposed to later in time than region R.

Then my proposed locality assumption LOC2 is:

LOC2: “If SR is proved true under the condition that L2 is freely chosen in region L then SR must be true also under the condition that L1 is freely chosen there instead.”

That is, LOC2 asserts that “If Line 5 is true then Line 6 is true”, where Line 6 is:

Line 6: “If L1 is performed then statement SR is true.”

The three essential points are:

1) LOC2 is an assertion about the *truth* of the statement SR, which is a conditional statement whose premise is that R2 is performed and the outcome is +; it it not an assertion that some outcome, or *value*, is fixed in nature.

2) No outcome of the experiment in region L is mentioned; the only conditions pertaining to outcomes (*i.e., values*) occur within the statement SR, which is an assertion of the existence of a *correlation* between possible outcomes of two alternative possible measurements in region R.

3) I claim that LOC2 is a locality condition: it expresses the condition that the property described by SR, which asserts the existence of a certain correlation between outcomes of possible measurements in region R, cannot depend upon which experiment is freely chosen later in region L

Unruh makes his contradictory claim in the second paragraph quoted above:

"causality cannot be used to argue that the inferred fact of the value of [the unmeasured quantity] must be independent of what was measured [faraway]."

However, this wording contains an essential ambiguity: it does not distinguish between two cases that are structurally very different, due to the different character of the inference that is involved. Unruh justifies this claim by considering one of these cases, but applies it to the other case.

The case in which the claim is justified is the one in which one infers the existence of an actual value in one system from the value measured on the faraway system. That is the usual familiar case.

But LOC2 does not claimed that some quantity associated with an unperformed experiment has an actual value. LOC2 is a different kind of claim: it asserts the *truth* of a statement that has a condition and a counterfactual consequence. It does not assert the factual *value* of an unmeasured quantity that can be direcly inferred from the knowledge of the outcome of an experiment performed faraway.

This may seem like a distinction too fine to matter. But it does matter. For no reality condition alien or contrary to quantum thinking is required to give a meaning to LOC2 that: 1) is completely and naturally specified by the words in the statement that define it; and 2) entails that a failure of LOC2 would mean the existence of some sort of action or influence backward in time.

In the way of speaking used by Dirac, Heisenberg, most quantum physicists, and occasionally even Bohr, if one of these experiments is performed then nature produces (or chooses) an outcome. Statement SR, expressed in this language, asserts that:

SR': "If under the condition that R2 is performed in region R nature produces outcome + in region R, then if R1 had been performed there, instead of R2, nature would have produced there the outcome –."

The concept of "what would have happened" if the free choice in region R had gone the other way was introduced in LOC1, and it arises not from any assumption of determinism, but as an expression of the idea that what has already happened at the macroscopic level, and been observed by a human observers, and been recorded in some memory device, cannot depend upon a later free choice by a faraway experimenter as to which experiment he will perform at some still later time.

Statement SR' has a meaning independently of whether it can be proved under certain conditions on the predictions of quantum theory. Generally this condition SR' is not true, and can be proved false independently of which experiment is performed in region L. But under the special circumstances of the Hardy experiment the property specified in SR' can be proved to hold under the condition that L2 be performed, without any condition on what the outcome of that experiment L2 is.

One cannot prove in the same way that the property described in SR' would necessarily hold also if the later free choice had gone the other way. But I believe that if SR' necessarily holds if the later free choice is L2, but would fail to hold if that later free choice had gone the other way, then there must be *some sort* of backward-in-time effect of that later free choice.

This argument does not involve any idea of reality alien to quantum theory. It does not require, as Unruh appears to claim, and it does not even suggest, that nature has a hidden variable that specifies what the outcome of R1 would be, independently of any outcome of any experiment. SR' asserts rather that there is a *correlation* between the outcomes of different alternative possible measurements. Correlations between outcomes of possible measurements are a standard feature of quantum theory, and the extension of such correlations to alternative possible measurements follows in the present case from the locality condition LOC1, which asserts a trivial correlation (nondependence) of the outcomes of a certain measurement on a free choice between two (faraway) alternative possible experiments. The correlation specified SR' follows, in case L2 is performed, from three correlations linked in tandem.

This detailed examination shows that Unruh's argument does not identify in my proof any tacit or hidden reality assumption that is alien to the principles of quantum theory.

References

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