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What is the Problem in the Locality Problem?

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In connection with my previous paper "Locality, Reflection, and Wave–Particle Duality" [Found. Phys. **17**, 813 (1987)], *in this paper I distinguish explicitly, in the locality problem, between assertions, deductively established results, interpretations, intuitions, and facts. This clarifies the structure of the problem.*

1. INTRODUCTION

In a recent work[1] I have brought into evidence a new type of causality conceivable for hypothetical hidden processes underlying spin measurements on pairs: a reflexive, double-way causality, carrying influences both from the object-state to the measuring devices and from the measuring devices to the object-state. In the present note, very briefly, nearly telegraphically, I shall add new specifications concerning the relations between Bell's theorem[2] and the concept of reflexive causality, and I shall indicate the consequences of these relations. This yields an analyzed perception of the structure of what is called the "locality" problem.

2. GENERALITY OF BELL'S REPRESENTATION AND SIGNIFICANCE OF BELL'S PROOF

Bell's proof compares two predictions, the quantum mechanical prediction concerning spin measurements on pairs of zero total spin, and the prediction entailed by a causal and Einstein-separable representation

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asserted by Bell for hypothetical hidden processes underlying the measurement operations presupposed by the mentioned quantum mechanical prediction.

Now, Bell's representation of these hidden processes is just a posit. It is asserted directly. Neither experimental facts nor some other arguments are invoked in favor of the adequacy or the generality of this representation. Afterwards, Bell's proof establishes *non*compatibility between Bell's representation and quantum mechanics, this last being confirmed by the experimental facts. So Bell's proof, associated with the experiments performed in order to test the proof, lead *a posteriori* to the conclusion that the representation posed by Bell as the basis of his theorem is *not* factually true.

The general reaction to this conclusion is to admit that it establishes incompatibility between quantum mechanics and Einstein-separable causality, and to explain and represent this incompatibility.

However, in the specified conditions, a primordial question is the following: *What obliges one to accept precisely Bell's representation? Is this representation of hypothetical causal and Einstein-separable processes the most general one conceivable? Does it include any other conceivable causal and Einstein-separable representation?*

It is obvious that this question has crucial importance for the significance of Bell's proof: Bell's proof opposes indeed quantum mechanics, to Einstein-separable causality, only inasmuch as Bell's representation includes indeed *any* conceivable causal and Einstein-separable model. If, on the contrary, it is possible to specify at least one other such model which is not contained in Bell's representation, then ipso facto Bell's representation reveals the status of a particular causal and Einstein-separable representation, and Bell's proof entails only the incompatibility between quantum mechanics and this particular representation. So, as long as the question of the degree of generality of Bell's representation has not been clearly answered, any explanation or representation of the incompatibility between quantum mechanics and Einstein-separable causality, asserted on the basis of Bell's proof, is premature.

Now, the realm of the physical phenomena, on the one hand, and the realm of the conceivable, on the other hand, are immensely rich (ensembles probably richer than that of the functions). Therefore the *a priori* chance that precisely the representation posed by Bell be really "the" most general one conceivable seems to be quasi-null and, I dare say, a naive notion.

Nonetheless, for a very long while I remained unable to *specify*, for hypothetical hidden processes underlying spin measurements on pairs, a causal and Einstein-separable model which is not integrable in Bell's representation. So I remained unable to contest its maximal generality.

Progressively, however, the obstacles dissolved, corroded by attempts stemming from a straightforward remark: Since the causal and Einstein-separable representation directly posed by Bell is not compatible with quantum mechanics, a hint concerning an eventually conceivable other causal and Einstein-separable representation, not includable in Bell's one, might be obtained by researching what type of causality—if any—*is* compatible with quantum mechanics.

3. A REFLEXIVELY CAUSAL EINSTEIN-SEPARABLE REPRESENTATION, AND ITS CONSEQUENCES

By analyses exposed in detail throughout pages 814–826 of the mentioned previous work[1] I have brought into evidence the fact that *the quantum mechanical prediction from Bell's theorem involves the physical assumption of reflection phenomena*, this assumption being hidden inside the formalism, encoded cryptically in superposition writings, combined with representations by tensor products of abstract spaces.

I have then incorporated this particular conclusion, concerning specifically spin measurements on pairs, in a quite general (and rather obvious) principle, "the principle of reflected dependence" (page 826). According to this principle, because *the measuring devices act also as obstacles*, "As soon as a measurement of an observable A involves several sets of measuring devices $D_{i\mathrm{A}}$, $i = 1, 2,...$, if one of these sets, $D_{k\mathrm{A}}$, produces by reflection of the object-system state a geometric shadow which intersects the spatial domain occupied by another set $D_{q\mathrm{A}}$, the probability for registering via $D_{q\mathrm{A}}$ a value V_j of A depends in general on characters of $D_{k\mathrm{A}}$."[2]

Once this principle of reflected dependence has been perceived, suddenly it becomes clear that Bell's representation, via the "locality" condition, banishes indistinctly any model from a whole class, namely *the class of* reflexive *causal evolutions, carrying influences, with* any *velocity, supraluminal or infraluminal, both from the object state to the measuring devices, and from the measuring devices to the object state.* When it is referred to this class of reflexively causal evolutions, by contrast, Bell's representation appears now as the representation of *a particular class of*

[2] I stress that the physical assumption of reflection phenomena does not necessarily entail the presence, in the formal representation, of non-null quantum mechanical reflection coefficients. Often—especially in the case of a representation of a several-systems system—the assumption of reflection phenomena is encoded exclusively in superposition writings. So the physical assumption of reflection phenomena corresponds to a domain of circumstances which overflows the domain corresponding to quantum mechanical descriptions that bring in quantum mechanical reflection coefficients.

causalities, namely the class of one-way *causal evolutions, carrying influences only from the object-state to the devices which produce the observable results. Any reflexive feedback effect able to influence the observable results is tacitly posed to be inexistent, namely, by the fact that there is no element of representation reserved for such an eventual effect: the descriptional dimension where a representation of an eventual reflexivity of causality might be embedded is not conceived, it is lacking in Bell's representation.*

Of course, not all the models from the class of reflexively causal models are also Einstein-separable. But some of them are. And these, in consequence of their reflexively causal character, violate Bell's condition of "locality," thus being *non*local in Bell's sense. So they are causal and Einstein-separable models which escape Bell's representation, hence also Bell's proof.

Indeed, I have constructed explicitly such a model (pages 828–833) which is clearly causal (reflexively) and also clearly Einstein-separable, and which—nevertheless—also quite clearly, is furthermore nonlocal in Bell's sense, not because it involves supraluminal velocities (which it does not, by construction), but because it is reflexively causal. This model cannot be imagined to be factually true because, again by construction, it represents exclusively the corpuscular-like aspects of the microsystems, the wave-like aspects of these being deliberately left entirely nonrepresented. I proceeded in this way for methodologic reasons, namely in order to separate radically the syntactic question of what is deductively established, from any semantic qualification concerning the established result. Indeed—quite independently of its value of factual truth—the mere *conceptual possibility* of this model *suffices* for establishing that:

(a) The condition imposed by Bell on his causal representation, which he calls the "locality" condition and which he assumes, more or less implicitly, to be a formal equivalent of Einstein's condition of separability, is in fact only a particular modality for ensuring separability in Einstein's sense, a possible modality but not a necessary one, an unspecific modality which ensures Einstein separability by excluding altogether any reflexivity of the admitted causal processes, infraluminal reflexivity, as well as supraluminal reflexivity. While Einstein's condition of separability restricts exclusively the velocity values of reflexive processes excluding only supraluminal reflexivity. Consequently:

(b) The concept of Einstein-separable causality has to be distinguished from the concept of causality "local" in Bell's sense. The terms "local" and "locality" associated *a priori* with Bell's condition and suggesting a strict translation of Einstein's concept of separability—i.e., a specific relation with the velocity values of the reflexive processes—are a source of confusion because in fact Bell's condition entails no defined relation whatsoever with the values of the velocities of the physical processes corresponding to Bell's representation.

(c) The constructed model, even though it is both causal (reflexively) and Einstein-separable, escapes Bell's representation because it is nonlocal in Bell's sense, hence it escapes also Bell's proof which—essentially—is founded on the condition of locality in Bell's sense.[3] Thus, contrary to what is currently admitted:

(d) Bell's proof does not *establish* the incompatibility of quantum mechanics with *any* Einstein-separable causality. (Nevertheless, of course, this incompatibility might exist.)

This is an important first conclusion (which can be reobtained with a variant of the same model where no use is made of quantum mechanical reflection coefficients).

One might feel a tendency to refuse this conclusion because it is founded on a too simple model which—decidedly—cannot be accepted as factually true. But such a tendency cannot last. To begin with, note that Bell's model also is not factually true, which does not in the least hinder it from being conceptually significant. Furthermore, as I have stressed before, the role assigned to the constructed model, deliberately, is radically independent of any valuation of its factual truth. The aim of the model is exclusively to prove, by construction of an example, the *conceptual* possibility of representations which are causal and Einstein-separable and which nevertheless are nonlocal in Bell's sense, thus transgressing Bell's representation and escaping Bell's proof. Obviously this suffices for entailing all the consequences enumerated above. The study of the various semantic aspects of what is called the "locality" problem—factual truth of the represented processes, physical significance of the formal writings, what is experimentally observed, what explanations the experimental data do admit, etc.—one by one, can and must be clearly distinguished, and treated separately, from the syntactic aspects of this problem. Only in this way can one hope to obtain an analyzed view of the structure of this complex problem.

4. DEDUCTIONS, ASSERTIONS, INTERPRETATIONS, INTUITION, AND FACTS IN THE "LOCALITY" PROBLEM

So the possibility, for hypothetical hidden processes underlying spin measurements on pairs, of a causal and Einstein-separable model which is nonlocal in Bell's sense, is tied with certain qualifications concerning Bell's theorem. Let us now review and complete these qualifications.

[3] I have also shown explicitly how this model escapes Bell's proof.

Bell's inequality is an uncontestable syntactic fact, the *deductively established* part of the theorem: Bell's representation of hidden processes underlying spin measurements on pairs is indeed incompatible with quantum mechanics.

But Bell's representation is just posed, without any exposed previous arguments, and it is *a purely assertive element* of the theorem.

The causal and Einstein-separable representation posed by Bell is subject to a well-known condition of mathematical independence, which Bell qualified as a condition of "locality," suggesting at the beginning of his work that it constitutes a formal *equivalent* of Einstein's principle of separability. Correlatively, Bell has suggested at the end of his work that violation of the inequality proved by him would *necessarily* indicate supraluminal influences violating Einstein's relativity. But these two connections with Einstein's theory—no matter whether they are factually true or not—are not demonstrated, they are just a credo concerning the factual substrata toward which points the formalism from the theorem; they are an intuitive *a priori* opinion concerning these substrata, an *interpretation* of the formalism from the theorem. Now, the possibility of a (reflexively) causal and Einstein-separable model which does not satisfy Bell's restrictive condition shows that Bell's interpretation of his formalism cannot be accepted. The condition by which Bell restricted his representation does not exclude specifically only the supraluminal reflexive influences, as Einstein's principle does. It excludes indistinctly any reflexive influences, introducing no defined relation with the values of the velocities of the processes involved. *Bell's restriction could be adequately qualified as a condition of "nonreflexivity." Calling it a condition of "locality" transgresses its content and thereby produces confusion.* Hence Bell's proof does not concern specifically Einstein separability (i.e., supraluminal reflexivity); it concerns indistinctly all the reflexivities.

So, in Bell's work, an uncontestable core of a deductively established incompatibility has been combined with a directly asserted representation, and with interpretations connecting the formalism of the work with Einstein's theory. Under the pressure of the high density of Bell's style, the deductively established, the simply asserted, and the interpretations have merged together in the minds of physicists and have crystallized there as an apparent monolith of entirely demonstrated truth. This unification created a long-lasting state of confusion which has been highly fertile. However, the possibility of a causal and Einstein-separable model which is not local in Bell's sense dissolves now this unification and brings into evidence an analyzed qualification of the conceptual situation which, in its turn, might also be fertile. This analyzed qualification can be summarized as follows.

The deductively established abstract significance of Bell's inequality is that quantum mechanics is not compatible with the absence of a crossed dependence. In consequence of the nonspecificity of Bell's condition of "locality," with respect to the involved velocity values, this incompatibility does not admit of an interpretation as a definite qualification of the relationship between quantum mechanics and relativity. But it does admit of another physical interpretation, namely as a definite qualification of the relationship between quantum mechanics and causality. *Indeed Bell's proof can be regarded as a formal proof of the incompatibility between quantum mechanics and one-way, nonreflexive causality; and if it is referred to the physical concept of reflected dependence, Bell's proof can be interpreted still more specifically as a proof* per absurdum *of the principle of reflected dependence, fundamentally involved in quantum mechanics.*

Now, this correct abstract significance of Bell's proof and these possible physical interpretations of it are very important. They are at least as important as those erroneously assigned to it. Indeed, a general mathematical demonstration concerning the type of causality compatible with quantum mechanics is a quite remarkable achievement which, if it were still absent at the present time, would probably, *a priori*, seem to be unrealizable. Therefore it is still more important to finally perceive the abstract significance of Bell's proof and its possible physical interpretations as what they effectively are. Their false understanding not only hampers their correct understanding but, moreover, if it lasts too long, unavoidably will transmute from a ferment of thought into an obstacle in the way of pertinent new conceptualization.

As to the experimental investigations performed by Aspect and his collaborators in order to test Bell's inequality, their results *transgress* the question defined *deductively* by Bell's theorem, namely whether the inequality is factually true or not. Reaching beyond the deductively established, Aspect's results confirm directly the *intuition* which generated Bell's work, namely that Einstein's principle of separability somehow fails to apply to quantum mechanics (which is true, in a sense defined below). We are here in the presence of a striking illustration of the ambiguous but profound and decisive role played by intuition in the evolution of scientific research. Since Bell's model does not specifically translate Einstein's principle, Bell's demonstration and its possible significances do not specifically concern Einstein's principle. *Nevertheless* the language and the verbal comments associated with them do refer to Einstein's principle, and thereby, instead of vehiculating exclusively the strict content of Bell's proof, they vehiculate also Bell's intuition that supraluminal velocities might be involved in the considered phenomenon. This happy transgression led to

Aspect's experiments with *flipping* devices, which prove factually that supraluminal crossed effects are indeed involved in certain microscopic processes.

It might then seem at first sight that—*whatever* be the strict abstract significance of Bell's deductively established result, and its possible interpretations—Aspect's experiments now "prove factually" that quantum mechanics is incompatible with relativity. This, however, would be a hasty conclusion. Even if quantum mechanics does involve supraluminal velocities, the relationship between quantum mechanics and relativity is much too complex for admitting such a simple characterization, in terms of a clear-cut diagnosis of logical compatibility or incompatibility.

5. A CONSTRUCTIVE PROBLEM OF UNIFYING MODELIZATION

Before admitting the incompatibility between quantum mechanics and Einstein separability on the *sole* basis, now, of Aspect's experimental results, and developing consequences of this *logically unproved* incompatibility, it seems imperative to take precautions. We have to explore first seriously the possibility of a coherent constructive unification of quantum mechanics and relativity, via a convenient modelization of the microphenomena involved in Aspect's results, a modelization endowed with a reflexively causal character, as is required by the principle of reflected dependence implied by the quantum mechanical formalism.

The possibility of a coherent unification of quantum mechanics and relativity certainly cannot be eliminated *a priori*. Louis de Broglie's thesis, which was one of the main germs of quantum mechanics, drew its fertility precisely from the fact that it offered a first "quantic" model of a microsystem, which was derived from *relativistic* conditions and which nevertheless *entailed* supraluminal influences. Even if de Broglie's model was flawed by weaknesses and therefore failed to subsist as an explicitly accepted model, it nevertheless has been incorporated into the formalism of quantum mechanics. Its essence remains encoded there. *At least to a certain extent, quantum mechanics, relativity, and supraluminal influences are mutually consistent. But to what an extent exactly?* The positivistic interdiction of any modelization has preserved a conceptual void around this question.

Now, the fact that Bell's proof does not establish that quantum mechanics is incompatible with Einstein's principle of separability, obviously does not entail the opposite assertion, that quantum mechanics is compatible with this principle. Furthermore, my first reflexively causal and Einstein-separable model for hypothetical processes underlying spin measurements on pairs, which permitted me to analyze Bell's theorem, cannot be imagined to be factually true, because it does not take into account the existence of wavelike manifestations of the microsystems. Hence, the question remains open whether or not it is possible to construct another reflexively causal model which is separable in Einstein's sense and which, moreover, is also acceptable as factually true.

I explored this question in the second part (pages 836–850) of my quoted work.[1]

This exploration first revealed, in Einstein's formulation of his principle of separability, insufficiencies which confine its bearing. For instance, Einstein's concept of separability simply cannot *concern* a de Broglie microsystem, involving an extended de Broglie wave; it can be neither asserted nor negated concerning such a type of object; it simply does not reach such a concept of object; it does not touch it. In consequence of this, *the problem of the compatibility between quantum mechanics and Einstein separability is for the moment* devoid *of definition.* So, though Bell's intuition that Einstein separability does not apply to quantum mechanics is confirmed, one cannot assert an "incompatibility." All that can be asserted is that Einstein's principle will have to be reexamined and reformulated. Namely, it will have to be reformulated in such a way as to permit explicitly, for the corpuscular waves, the supraluminal phase velocities implied by the quantum mechanical formalism, without thereby compromising the essence of relativity. Since *relativistic considerations* led de Broglie to the assertion of these supraluminal velocities, this *must* be possible. In consequence of the implication of supraluminal phase velocities of corpuscular waves, quantum mechanics asserts indeed a certain peculiar sort of "nonseparability," but which cannot be *logically* opposed to Einstein's unachieved concept of separability. A *purely deductive approach cannot suffice. A constructive approach will be necessary. The construction will probably produce a unifying prolongation of both relativity and quantum mechanics.*

I then tried to deepen the perception of the various possible contents of the class of reflexively causal representations: What would be the characteristics of a reflexively causal evolution of a de Broglie-type object, to which are assigned both a capacity of corpuscular-like manifestations and a capacity of wavelike manifestations, each of these two types of capacities covering an extended space-time domain? How can one define, for reflexively causal evolutions of such complex objects, the compatibility and the incompatibility with relativity? *How could Aspect's results be modelled in terms of such objects undergoing reflexively causal evolutions?*

Finally, I have specified, for hypothetical processes underlying spin measurements on pairs, the main lines of a reflexively causal representation where the microsystems—and also creation of pairs of microsystems—are assigned a model of de Broglie's type. (Concerning this second representation, it is not possible to uphold that clearly it is separable in Einstein's sense, or that it clearly is not, for the reason already stated before that Einstein's principle, as it is formulated, simply cannot be confronted with the evolution of an object of the de Broglie type; i.e., it can neither be asserted nor negated relatively to such an object.) It seems that nothing proved, so far, hinders one from imagining this representation as being "true." But this, of course, is no more than an indication in favor of the possibility of a future, deeper and general unifying modelization.

I summarize:

At the present time, explanations or representations sanctifying the incompatibility between quantum mechanics and Einstein separability are premature. For the moment the problem, in what is still named the locality problem, is to attempt, beneath quantum mechanics and relativity, a clearly *reflexively* causal unifying modelization. Bell's representation is a model which, by its fertility, has demolished the positivistic interdiction of modelization beneath the quantum mechanical formalism. This is a victory. The started process of modelization must now be rectified and developed. Important elements in this direction might be found in existing works by Bohm and Hiley,[3] Vigier[4] and collaborators, Leon Cohen[5] and collaborators, D. Evrard,[7] this author,[6] and possibly others.

Bell's theorem, once correctly understood, suggests new efforts for a certain specified sort of constructive harmonization of quantum mechanics and relativity.

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