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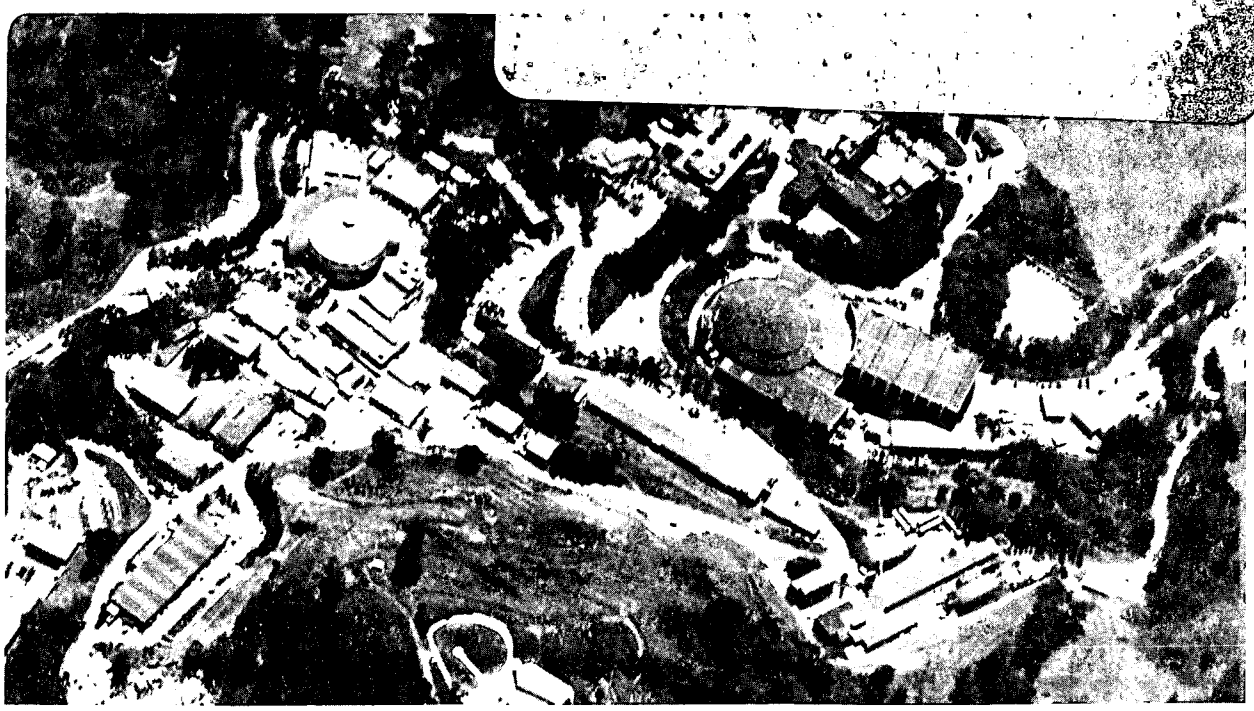

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Are Faster–Than–Light Influences Necessary? *

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1. Faster–than–light Influences and Signals

The question of whether influences act instantaneously over finite distances is as old as modern science itself. Newton, when he proposed his universal law of gravitation, was asked how the postulated force was transmitted. He declined to frame a hypothesis regarding the mechanism, but declared that anyone who believed that the force could act over a finite distance without an intervening medium had a mind not fit for the contemplation of the such matters. But in spite of Newton's conviction no significant progress was made on the question of action–at–a–distance for two centuries. Then Maxwell propounded his theory for the analogous problem of electric and magnetic forces. This theory entailed the existence of light, and correctly predicted its velocity. It also entailed that no electric or magnetic influence of a sufficiently tangible kind could be transmitted faster than light. During the present century Einstein, generalizing this result, formulated the principle that no "signal" could propagate faster than light.

A signal is a special kind of influence. It can be initiated by a human choice, which controls a far–away response. For example, the choice of whether or not to depress a telegraph key controls, under appropriate conditions, whether or not a device will sound at the other end of the telegraph line.

The human choice and the response it controls each can be localized in a corresponding spacetime region. A faster–than-light signal is a signal such that no point in the region of the response can be reached from any point in the region of the choice without moving faster than light. Relativity theory postulates the non existence of faster–than–light signals, but imposes no analogous requirement upon other conceivable kinds of influences.

2. The Spin–Correlation Experimentals

Einstein, Podolsky, and Rosen argued in their famous 1935 paper[1] that quantum theory did not provide a complete description of physical reality. Their argument was based on the analysis of a complicated experimental situation. David Bohm[2] later clarified the situation, by introducing a simpler experimental set–up that exhibited all the essential features. Bohm's "spin version" of the EPR experimental arrangement is the basis of the present considerations. It is described in the introductory part of this book, and need not be further discussed here.

One point should, however, be emphasized. My starting point, like that of EPR, is the assumption that the predictions of quantum theory for the experiments under consideration are valid. Some other contributions to this book start, instead, from the experimental data. Then questions concerning the counter efficiencies and the geometric details of those

particular experiments that have already been performed become relevant. But I start directly from the predictions of quantum theory. These predictions are, for the experiments under consideration, expressions of the core ideas of quantum theory: the possibility that they are seriously incorrect appears to me to be extremely unlikely.

One further stipulation should be made: in the experiment I am considering the particles in the two initial beams of identical spin 1/2 particles initially scatter near the center of a spherical array of counters. This array has two escape holes that allow some pairs of particles, which have scattered at 90^0, to escape. These escaping pairs i are numbered from 1 to N by fast electronics. The geometric arrangement is such that one particle from each pair i will enter a deflection device in a spacetime region R_1, and the other particle from the pair i will enter a deflection device in a spacetime region R_2. Detecting and recording devices are arranged so as to record in R_1, for each i from 1 to N, either $r_{1i} = +1$ or $r_{1i} = -1$, according to whether the particle from pair i is deflected "up" or "down" in R_1, relative to the preferred direction D_1 of the deflection device in R_1. The numbers $r_{2i} = \pm 1$ are similarly defined and recorded in R_2. A choice is made in R_1 between two alternative possible preferred directions, D_1' or D_1'', of the device in R_1, and a choice is made in R_2 between two alternative possible preferred directions, D_2' or D_2'', of the device in R_2. The two regions R_1 and R_2 are space–like separated, which means that the information about the choice of setting made by the experimenter in R_1 does not have time to get to region R_2 before the results $r_{2i} = \pm 1$ are recorded there, and vice versa, without traveling faster than light.

The choices of the experimenters in R_1 and R_2 are considered, for the purposes of this analysis, to be two independent free parameters. This does not mean that these choices are necessarily literally free and nonpredetermined. It means only that one is allowed, within the specific context of the analysis of the implications of the quantum theoretical predictions for these particular experiments, to treat the choices of the two experimenters as two independent free variables. These predictions are extracted from a quantum theoretical representation of the state of the two particles. The mathematical formalism used in this calculation has no representation at all of the processes of making choices that are going on in brains of experimenters: it involves only the states of various mechanical devices during those periods in which the particles are in or near these devices, not how the devices came to be in those particular states. The EPR analysis is, in this respect, identical to that of quantum theory itself, which also treats the choices of the experimenters as independent free variables, within the context of the study of these experiments.

For our purposes the important prediction of quantum theory pertains to the correlation

parameter defined by

$$c(r_1, r_2) = \frac{1}{N}\sum_{i=1}^{N} r_{1i} r_{2i}. \tag{1}$$

Since each r_{1i} and r_{2i} is, according to the definitions given earlier, either plus or minus one, each term in the above sum is also either plus or minus one. Thus the largest and smallest possible values of this sum are N and − N. Consequently, c must lie between plus one and minus one.

The relevant prediction of quantum theory is that if N is very large then the number c, computed according to the formula (1), will be very close to the number

$$\bar{c}(D_1, D_2) = -\cos\theta(D_1, D_2), \tag{2}$$

where $\theta(D_1, D_2)$ is the angle between the preferred directions, D_1 and D_2, of the deflection devices in R_1 and R_2, respectively.

An important special case is that in which the directions of D_1 and D_2 are the same. Then the angle $\theta(D_1, D_2)$ is zero, and $\bar{c}(D_1, D_2)$ is minus one. The only way in which the number c computed according to formula (1) can be minus one is for every term in the sum to be minus one. This means that for every value of i the signs of r_{1i} and r_{2i} must be opposite: if the deflection in R_1 is "up" then the deflection in R_2 is "down", and vice versa. This means that if the directions of D_1 and D_2 are the same then the deflections in R_1 and R_2 are perfectly "anti–correlated": an "up" deflection in one region is (almost) invariably accompanied by a "down" deflection in the other region, and vice versa.

In the spin version of the EPR argument the alternative possible directions D_1' and D_1'' differ by 90^0, but D_1' is the same as D_2', and D_1'' is the same as D_2'' .

Einstein, Podolsky, and Rosen constructed a simple–looking but actually rather subtle argument for the incompleteness of the quantum–mechanical description of physical reality. Before describing the EPR argument I shall describe a naive argument that appears to lead to the same conclusion.

3. The Naive Argument

Suppose that the choices of directions in R_1 and R_2 were such that D_1 and D_2 were the same. Then the deflections in R_1 and R_2 would be perfectly anti correlated, as discussed above: each deflection "up" in one region would be paired with a deflection "down" in the other region, and vice versa.

There is a natural way to explain this perfect anti–correlation: for each pair i the decisions as to whether the deflections will be "up" or "down" in each of the two region

R_1 and R_2 are fixed already at the time and location of the initial collision between the two particles of this pair. The information about these decisions can then be carried by the particles into the regions R_1 and R_2 where the deflections occur. In this way the perfect anti–correlation is understood in a completely natural way without requiring any faster–than–light transfer of information.

There is an alternative way of understanding the perfect anti–correlation. In this second scheme the decision as to whether the particle is deflected up or down in R_1 is made only during the processes of deflection, detection, and registration in R_1. In this case the information regarding this choice made in R_1 cannot get to R_2 without traveling faster than light. And the analogous statement holds also for the choice of result made in R_2: the information about this choice cannot get to R_1 without traveling faster than light. Thus there is, in this second scheme, no way to understand the existence of the perfect anti–correlation, without allowing faster–than–light transfer of information. If one rules out such transfers then one also rules out the possibility that the choices of results are fixed in R_1 and R_2. This drives one back to the original supposition that the choices of results that will eventually appear in R_1 and R_2 are fixed already during the initial scattering of the two particles.

This natural solution leads, however, to a problem. In the experimental situation under consideration here the choice between the directions D_1' and D_1'' is not made until a time long after the original collision has taken place. And the same is true of the choice between D_2' and D_2''. Thus the information about which experiments will eventually be performed in the two regions R_1 and R_2 is not available at the time of the initial scattering. (Here it has been assumed that the information about the choice of experiment performed in either region can propagate only forward in time.) Consequently, the fixings made during the initial scatterings must fix the results of <u>both</u> of the then–existing possibilities for the experiment that will eventually be chosen in each region.

This latter conclusion entails that the quantum theoretical description is incomplete. For this conclusion amounts to admitting the predetermination of the results of several experiments, only one of which can actually be performed. And these alternative possibilities are, according to the quantum formalism, incompatible possibilities. Therefore quantum theory has no way to represent simultaneously a well defined result for all of these alternative possible measurements. So if these various results were in fact, simultaneously well defined, then the quantum theoretical description, being unable to represent all this information, would necessarily be incomplete. This is the naive form of the argument for the incompleteness of the quantum theoretical description.

4. Orthodox Responses to the Naive Argument

To understand the response of the orthodox quantum theorist to the naive argument it is necessary to recognize that the orthodox Copenhagen interpretation has two levels, which I call the "strict" and "informal" levels. A principal element of both is that the quantum formalism is to be regarded as merely a set of rules for calculating connections between certain kinds of observations. In the words of Bohr, "Strictly speaking, the mathematical formalism of quantum theory . . . merely offers rules of calculation for the deduction of expectations pertaining to observations obtained under well-defined conditions specified by classical physical concepts".[3] . . . "the formalism does not allow pictorial representation along accustomed lines, but aims directly at establishing relations between observations obtained under well defined conditions".[4] The attitude that demands rigorous adherence to this point of view, and admits no discussion at all of what is "happening", I call the "strict" interpretation.

Bohr's words are, however, fully compatible with the idea that our observations are observations of things that are actually "happening" in the external world, on the macroscopic level. But Bohr carefully avoided making specific ontological commitments on these "happenings". Heisenberg, on the other hand, was more forthcoming. He speaks of transitions from the "possible" to "actual" and says: "If we want to describe what happens in an atomic event, we have to realize that the word 'happens' can apply only to the observations, not to the state of affairs between observations. It applies to the physical, not the psychical act of observation, and we may say that the transition from the 'possible' to the 'actual' takes place as soon as the interaction of the object with the measuring device has come into play; it is not connected with the act of registration of the result in the mind of the observer. The discontinuous change in the probability function, however, takes place with the act of registration, because it is the discontinuous change in our knowledge in the instant of registration that has its image in the discontinuous change in the probability function".[5] He speaks also of the probability function as representing "tendencies" or "potentia" for these actual happenings or events, which take place when the interaction of the object with the measuring device has come into play.

This idea that the transition from the "possible" to the "actual" takes place when the interaction of the object with the measuring device comes into play leads to the second scheme described above for understanding the existence of the strict anti–correlations. The problem with that second scheme was that it required faster–than–light transfer of information.

Heisenberg deals with this question in his 1929 book, The Physical Principles of the

Quantum Theory. He discusses there the simpler situation in which a photon wave–packet strikes a half–silvered mirror, and divides into two packets that move into separated regions. He then says "if now an experiment yields the result that the photon is, say, in the reflected part of the packet, then the probability of finding the photon in the other part of the packet immediately becomes zero. The experiment at the position of the reflected packet then exerts a kind of action (reduction of the wave packet) at the distant point occupied by the transmitted packet, and one sees that this action is propagated with a velocity greater than light. However, it is also obvious that this kind of action can never be utilized to transmit a signal so that it is not in conflict with the postulates of the theory of relativity".[6]

If, in accordance with Heisenberg's ideas, the probability function is regarded as representing tendencies for the macroscopic happenings, such as the firings of particle counters, then the sudden "reduction of the wave packet" represents an abrupt change in tendencies at the distant point, and hence an immediate physical influence of some sort. The anti–correlation of the results in R_1 and R_2 that occur in the EPR–Bohm experiments can then easily be explained – and reconciled with the idea that the result of the experiment is not fixed until the interaction of the object and the device has come into play – by exploiting the abrupt change in tendencies in the distant region. The naive argument for the incompleteness of quantum theory is thereby dissolved by considerations that were a standard part of quantum theoretical thinking already in 1929. However, this way of thinking admits the existence of faster–than–light influences. But the information transmitted faster–than–light pertains to nature's selections, rather than the experimenter's choices.

Heisenberg's approach admits the existence of faster–than–light influences, but not faster–than–light signals. However, the more usual strategy is to retreat to the strict interpretation, and simply refuse to accept the idea that nature's selections can be localized. Then the naive argument loses its force, because the quantum theorist simply refuses to recognize the categories of things upon which the argument is based.

5. The EPR Argument

The EPR argument is a modification of the naive argument. It is designed to invade the seemingly impregnable position of the strict interpretation. The EPR argument meets the quantum theorist on his own ground, and on his own terms. For only in this way can the argument carry weight in the minds of these theorists.

The quantum theorist's terms are the acceptance of nothing other than: (1), the freedom of the experimenters to choose the experiments they will perform, and (2), the validity of the predictions of quantum theory.

Restriction imposed by locality requirements can be entertained, but restrictions on influences must be confined to the influences of human choices: human choices can be assumed to be localized in the regions in which they are made, and it can be assumed that no such choice made in one region can influence anything in a second region if the second region can be reached from the first only by traveling faster than light.

The aim of the EPR argument is to answer (in the negative) the question posed in their title: Can quantum mechanical description of physical reality be considered complete? Thus EPR must give meaning to the words "physical reality". They do this by introducing their famous criterion of physical reality: "If, without in any way disturbing a system, we can predict with certainly (i.e., with probability unity) the value of a physical quantity, then there exists an element of physical reality corresponding to that physical quantity". EPR discuss this criterion of physical reality, and argue that it accords with the ideas of both classical physics and quantum theory.

Let the two alternative possible physical quantities pertaining to region R_1 be denoted by r_1' and r_1''. And let the two alternative possible physical quantities pertaining to region R_2 be denoted by r_2' and r_2''. The prime and double prime are coordinated to the superscripts on D_1' and D_1'', and on D_2' and D_2''. Thus each possible value for r_1' is a set of numbers $r_{1i}' = \pm 1$, etc., and the equalities $D_1' = D_2'$ and $D_1'' = D_2''$ lead, via equations (1) and (2), to

$$r_{1i}' = -r_{2i}' \quad \text{all} \quad i \quad \text{if} \quad D_1 = D_1' \quad \text{and} \quad D_2 = D_2' \tag{3}$$

and

$$r_{1i}'' = -r_{2i}'' \quad \text{all} \quad i \quad \text{if} \quad D_1 = D_1'' \quad \text{and} \quad D_2 = D_2''. \tag{4}$$

These equations represent, algebraically, the strict anti–correlations that were discussed above.

The EPR argument, in their own words, except for appropriate replacements of symbols, is this: by measuring either r_1' or r_1'' we are in a position to predict with certainty [by using either (3) or (4)], and without in any way disturbing the system in R_2, either the value of r_2' or the value of r_2''. In accordance with our criterion of physical reality, in the first case we must consider r_2' as being an element of physical reality, in the second case r_2'' is an element of physical reality. Thus either r_2' or r_2'' is an element of physical reality depending on whether we measure r_1' or r_1'' in region R_1. But maintaining that either r_2' alone or r_2'' alone is an element of physical reality, depending on what we measure in R_1, would make "the reality of r_2' and r_2'' depend upon the process of measurement carried out in region R_1. No reasonable definition of reality could be expected to permit this."[1] Thus r_2' and r_2'' must be simultaneous elements of physical reality. This immediately entails, for

reasons already explained, the incompleteness of the quantum theoretical description of physical reality.

6. Bohr's Rebuttal

Rosenfeld has described the reaction in Copenhagen that the EPR paper evoked.[7] Bohr's initial attempts at an answer were not satisfactory. After six weeks of effort his reply was completed. But this reply [8] was addressed mainly to the question of the consistency of the quantum–theoretical description, in the experimental situation discussed by EPR, not to the EPR argument itself, which questioned not the consistency but rather the completeness of the quantum–theoretical description.

Bohr's rebuttal to the EPR argument itself was this:

> "From our point of view we now see that the wording of the above–mentioned criterion of physical reality proposed by Einstein, Podolsky and Rosen contains an ambiguity as regards the meaning of the expression "without in any way disturbing a system." Of course there is in a case like that just considered no question of a mechanical disturbance of the system under investigation during the last critical stage of the measuring procedure. But even at this stage there is essentially the question of *an influence on the very conditions which define the possible types of predictions regarding the future behavior of the system.* Since these conditions constitute an inherent element of the description of any phenomenon to which the term "physical reality" can be properly attached, we see that the argumentation of the mentioned authors does not justify their conclusion that quantum–mechanical description is essentially incomplete."

The point of this rebuttal was to tie "physical reality" to what can be predicted about a system, and then to maintain that, since our predictions pertaining to region R_2 depend upon what we do in R_1, the physical reality in R_2 is disturbed by what we do in R_1.

The subtlety of Bohr's response testifies to the strength of EPR's argument: Bohr evidently found no simple, adequate reply. In the end he denied the EPR locality assumption that what we do in one region leaves undisturbed the physical reality in the other region. Heisenberg's approach also denies this assumption: he accepts the existence of faster–than–light actions that are not faster–than–light signals. The fact that the responses of both Bohr and Heisenberg effectively reject the EPR locality assumption suggests that what we have here is some subtle sort of faster–than–light connection. This is exactly what a deeper analysis, based on the work of Bell, appears to show.

7. Bell's Theorem

The problem of faster–than–light influences remained dormant in the minds of most physicists until it was stirred up in 1965 by a paper written by John Bell.[9] Bell began his paper by a brief account of the argument of EPR:

"Since we can predict in advance the result of measuring any chosen component of $\vec{\sigma}_2$ by previously measuring the same component of $\vec{\sigma}_1$ it follows that the result of any such measurement must actually be predetermined. Since the initial quantum mechanical wave function does not determine the result of an individual measurement, this predetermination implies the possibility of a more complete specification of the state. Let this more complete specification be effected by means of a set of parameters λ."

This version of the EPR argument introduces many elements that are not present in the carefully sculpted argument of EPR itself. These are "in advance", "previously", "predetermined", and "parameters λ". Bell put these extra ideas together to form the idea of a deterministic hidden–variable theory. This theory he subjected to a locality requirement, which demanded that the results that would appear in each region, under either of the conditions that might be set up there, must be independent of the choice made by the experimenter in the other region, which is space–like separated from the first. He then showed that no such local deterministic hidden–variable theory could reproduce all the statistical predictions of quantum theory for spin–correlation experiments of the kind we have been discussing. A key innovation was to consider not just the predictions associated with settings of D_1 and D_2 at 0° and 90^0, but to consider also some other appropriately chosen settings.

This result of Bell's did not immediately appear to have any great significance pertaining to the question of faster–than–light influences in nature. For the assumptions of determinism and of hidden variables seemed doubtful: orthodox quantum thinking explicitly rejects both of these ideas. However, both of these extra assumptions can, as we shall see, be stripped away.

8. Failure of Local Micro–Realism

The theorem of Bell has been extended by Clauser, Horne, Shimony, and Holt,[10] to a broader class of hidden variable–theories, which accommodate stochastic elements. Much of the work of these authors is concerned with experimental tests, and hence with problems connected to counter efficiencies, etc. These considerations do not concern us, since we are accepting the validity of the quantum predictions.

Locality conditions for these stochastic hidden–variable theories were introduced by invoking semi–classical ideas[11][12] at the microscopic level. These ideas suggested a certain hidden–variable factorized–form for the probabilities of coincidence counts.

In an effort to express in general terms the assumptions that underlie this proposed hidden–variable factorization property Clauser and Shimony[12] have considered the concept of realism:

"Realism is a philosophical view according to which external reality is assumed to exist and have definite properties whether or not they are observed by somebody".

In the consideration of quantum theory it is necessary to distinguish macro–realism from micro–realism. The Copenhagen interpretation of quantum theory is certainly compatible with macro–realism: it is compatible with the idea that our observations are observations of a macroscopic external reality created by myriads of macro–events of the kind discussed by Heisenberg. Of course, the strict Copenhagen interpretation enjoins us not to clutter quantum theory with superfluous ontological suppositions about the precise nature of these happenings. But it certainly allows their existence. Thus the general assumption of macro–realism does not take us outside the strict Copenhagen interpretation.

However, the ideas that underlie the justification of the hidden–variable factorization property of Clauser et al., are ideas about a microscopic level of reality that is totally alien to orthodox quantum theoretical thinking. Theories that satisfy this hidden–variable factorization property should perhaps be called local micro-realistic theories, instead of local realistic (or objective) theories, to emphasize the fact that they express certain ideas about the character of reality at the microscopic level that go far beyond the simple idea that external reality exists and has some well defined (macroscopic) properties whether or not they are observed by somebody.

Clauser and Shimony have noted that an assumption of physical realism underlies the argument of EPR. However, the EPR reality assumption is expressed by general principles that were designed to be compatible with orthodox quantum thinking. The EPR assumption is thus totally different in character from the semi–classical ideas about a local microscopic spacetime structures that underlie the hidden–variable factorization properties used by Clauser, Shimony et al.,

9. Failure of EPR Local–Realism.

The logical form of the EPR argument is this:

$$QM + (LOC + REALITY) \rightarrow CFD \tag{5a}$$

and

$$CFD \rightarrow QM \quad \text{IS INCOMPLETE.} \tag{5b}$$

That is, from the assumption that the predictions of quantum theory are valid, and certain combined assumptions about locality and physical reality, EPR conclude that the results of some unperformed (and mutually incompatible) experiments must be simultaneously well defined. (CFD = Counterfactual definiteness). This first conclusion, CFD, immediately entails, as noted by EPR, that the quantum–mechanical description is incomplete.

Simple arithmetic shows, as will be discussed presently, that[13]

$$CFD + LOC \rightarrow -QM \tag{6}$$

That is, counterfactual definiteness plus locality entails the nonvalidity of the predictions of quantum theory. The combination of this result with the first part of the EPR argument, (5a), entails

$$QM + (LOC + REALITY) + LOC \rightarrow -QM \tag{7a}$$

and hence, equivalently,

$$QM \rightarrow -(LOC + REALITY)_{EPR}, \tag{7b}$$

where

$$(LOC + REALITY)_{EPR} \equiv (LOC + REALITY) + LOC \tag{7c}$$

The LOC that occurs in (6), which applies within a context in which CFD holds, is not identical to the LOC that occurs in the combined assumption (LOC +REALITY) that occurs in (5a). But it expresses, within this CFD context, the same basic EPR locality idea that nothing in R_i can be disturbed by what the experimenters do in $R_j (j \neq i)$. This justifies the notation (7c).

This result (7b), which is based on (6), invalidates the EPR argument. For it shows that the general assumptions of the EPR argument are mutually incompatible. This purely logical argument eliminates the need for Bohr's epistemological rebuttal. It also yields a nonlocality result potentially far more interesting than the result of Bell. For it says that any theory that reproduces the predictions of quantum theory cannot satisfy the relatively weak locality and reality requirements that went into the EPR argument.

A key ingredient here is the one symbolized by Eq. (6). The meaning of this result is as follows: The CFD conclusion of the EPR argument (5a) says that the results of the two alternative possible experiments that might be performed in R_2 are simultaneously

well defined. And the same conclusion holds for the results of the two alternative possible experiments in R_1. (A slight elaboration of the EPR argument is needed when three different angles 0°, 90°, and 135° are used, instead of only two). Since the results in all four alternative possible combinations of experimental conditions are then simultaneously well defined we may construct a table that shows these values. One conceivable possibility for this table is shown in Fig. 1. Here N = 8, and the value of c, calculated according to (1), is shown. Also shown is the predicted value $\bar{c}$, calculated according to (2), for the following choices of the aimuthal angles that define the possible directions of D_1 and D_2:

$$\begin{aligned} D_1' &\sim \theta_1' = 0^o \\ D_1'' &\sim \theta_1'' = 135^o \\ D_2' &\sim \theta_2' = 0^o \\ D_2'' &\sim \theta_2'' = 90^o \end{aligned}$$

	(D_1', D_2')		(D_1', D_2'')		(D_1'', D_2')		(D_1'', D_2'')	
	r_1'	r_2'	r_1'	r_2''	r_1''	r_2'	r_1''	r_2''
i = 1	+1	−1	+1	+1	−1	−1	−1	+1
2	−1	+1	−1	+1	+1	+1	+1	+1
3	−1	+1	−1	−1	−1	+1	−1	−1
4	+1	−1	+1	−1	−1	−1	−1	−1
5	+1	−1	+1	+1	−1	−1	−1	+1
6	−1	+1	−1	+1	+1	+1	+1	+1
7	+1	−1	+1	−1	−1	−1	−1	−1
8	−1	+1	−1	−1	+1	+1	+1	−1
	c = −1		c = 0		c = .75		c = .25	
	$\bar{c} = -1$		$\bar{c} = 0$		$\bar{c} = .707$		$\bar{c} = -.707$	

$$c = \frac{1}{N}\sum_{i=1}^{N} r_{1i} r_{2i}$$
$$\bar{c}(\theta_1, \theta_2) = -\cos(\theta_1 - \theta_2)$$

Fig. 1 A table that shows one conceivable set of possibilities for the results of the four alternative possible experiments.

Once counterfactual definiteness is established the EPR locality idea can be formulated as the requirement that what would happen in either region, under either of the two alternative possible conditions that might be set up in that region, does not depend upon which of the two alternative possible experiments is chosen by the experimenters in the other region. This means that the set of results r_1' in R_1 does not depend upon the choice between D_2' and D_2'' made in R_2, etc.

In the first three pairs of columns the values have been arranged so that the value of c is close to the value $\bar{c}$ predicted by quantum theory. But the fourth case then shows a large disagreement. It is in fact easy to show[13],[14] that this is always the case, for all values of N, provided the angles $\theta_1', \theta_1'', \theta_2'$, and θ_2'' are selected in the way shown: for this choice of these angles there is no conceivable possible arrangement of the numbers $r_{1i}' = \pm 1$, $r_{1i}'' = \pm 1$, $r_{2i}' = \pm 1$, and $r_{2i}'' = \pm 1$ that satisfy both the locality conditions and the quantum theoretical predictions.

According to (7b) we may conclude from the mathematical result stated above that the assumptions that characterize EPR local–realism are invalid. However, the significance of this conclusion is not totally clear. This is because the EPR assumptions of locality and reality are expressed in a manner not suited to our present aim, which is very different from that of EPR. They wished to says something about "physical reality", and hence had to build their argument around a definition, or at least a criterion, of physical reality. And they wished to prove counterfactual definiteness in order to establish the incompleteness of the quantum theoretical description. We are not interested in defining "physical reality", or in proving either counterfactual definiteness or the incompleteness of the quantum theoretical description. Rather we wish to clarify the result suggested by the independent considerations of Heisenberg and Bohr, namely that the quantum aspects of nature are tied up to some subtle sort of faster–than–light connection. We shall need, therefore, to reformulate the results of this section in a way that circumvents the assumptions about "physical reality" that are not germane to our purpose. First, however, we shall introduce our criterion for the existence of an influence.

10. Criterion for the Existence of an Influence

In discussing the question of "influence" we are in a position similar to that of Einstein, Podolsky, and Rosen in their discussion of "physical reality": almost any symbol one writes down, or word one uses, can, from the point of view of the strict orthodox interpretation, prejudice the issue. No models, or words suggesting determinism or counterfactual definiteness can be invoked. One must base the considerations on general principles that are reasonable in their own right. The problem for EPR was to set forth a reasonable criterion

for "physical reality". Our problem is to set forth a reasonable criterion for the existence of an "influence".

Consider a theory that has a variable y, and an independent variable x. The idea that, within the structure imposed by this theory, the choice of the value of x does not influence y does not mean that within this structure the value of y must necessarily remain unchanged if the value of x is changed. For y might depend upon many things, and some of these, such as random variables, might not necessarily stay the same if x were changed. However, the idea that the choice of the value of x does not influence y does entail that, for each choice of the values of the other independent variables, the value of x can, within the constraints imposed by the theory, be varied over its domain without the value of y changing: the random variables could be left undisturbed. So we take as a sufficient criterion for the existence,within a theoretical structure, of an influence of the choice of the value of an independent variable x upon a variable y the condition that the theoretical constraints do not allow, for each choice of the values of the other independent variables, the value of x to be varied over its domain without the value of y changing. Similarly, we take as a sufficient condition for the existence of either an influence of the choice of the value of an independent variable x_1 upon a variable y_1, or an influence of the choice of the value of an independent variable x_2 upon a variable y_2, the condition that the theoretical constraints do not allow, for each choice for the values of the independent variables other than x_1, the value of the variable x_1 to be varied over its domain without the value of y_1 changing, and, conjunctively, for each choice of the values of the independent variables other than x_2,the value of the variable x_2 to be varied over its domain without the value of y_2 changing.

11. The Existence of Faster–Than–Light Influences

To discuss the influence of the choice of measurement performed in one region upon the decisions that nature can be forced to make in the other region we introduce a conceptual framework based on two assumptions. The first assumption is that, within the specific context of the analysis of the quantum theoretical predictions for the measurements under consideration here, the choices to be made by the experimenters can be regarded as free and independent variables. This does not mean that these choices are necessarily literally free, but merely that the causal determinants of these human choices are sufficiently divorced from quantum system under consideration as to have no essential bearing on the fact that measurements yield results that accord with the quantum predictions: the causal determinants of the human choices could be decoupled from the quantum system under study without disrupting the validity of predictions of quantum theory.

The second assumption is that, for each region, and for each of the two alternative possible measurements in that region, if that measurement is chosen then nature must make a definite decision between the alternative possible results of this measurement: two possible values for the outcome of a single decision are either equal or contradictory. This assumption excludes the many-worlds ontology, in which all of the alternative possible results are actually realized, and hence nature makes no decision.

A necessary condition for the noninfluence, within a theoretical structure, of the choice of the value of an independent variable x upon a variable y is that, within this structure, it be possible, for every choice of the independent variables other than x, to find a possible value y' for the variable y such that x can be varied over its domain with y held fixed at the value y'. For, even though there can be many factors that contribute to the determination of y but are not under theoretical control, such as intrinsic random variables and unspecified causal elements, the very idea that x is a free variable and that the choice of the value of x does not influence or disturb the variable y means that variations of x cannot <u>force</u> y to change: the various factors that enter into the determination of y, whatever they may be, must at least be <u>permitted</u> by the theory to remain unchanged as the value of x is varied.

Let $x_1 = \pm 1$ and $x_2 = \pm 1$ represent the alternative possible choices of the measurements in R_1 and R_2, respectively, and let $r_1(x_1)$ and $r_2(x_2)$ represent the <u>variables</u> measured in R_1 and R_2, respectively, if the choices of the measurements in these regions are x_1 and x_2, respectively. Each <u>possible value</u> $r_1'(+1)$ of the variable $r_1(+1)$ is a sequence of n values +1 or -1, etc. Thus a necessary condition for there to be no influence of x_1 upon $r_2(x_2)$, and no influence of x_2 upon $r_1(x_1)$, is that:

a) if $x_2 = +1$ then there is some possible value $r_2'(+1)$ for the variable $r_2(+1)$ such that x_1 can be varied over its domain $\{+1, -1\}$ without $r_2'(+1)$ changing,

b) if $x_2 = -1$ then there is some possible value $r_2'(-1)$ for the variable $r_2(-1)$ such that x_1 can be varied over its domain $\{+1, -1\}$ without $r_2'(-1)$ changing,

c) if $x_1 = +1$ then there is some possible value $r_1'(+1)$ for the variable $r_1(+1)$ such that x_2 can be varied over its domain $\{+1, -1\}$ without $r_1'(+1)$ changing,

and

d) if $x_1 = -1$ then there is some possible value $r_1'(-1)$ for the variable $r_1(-1)$ such that x_2 can be varied over its domain $\{+1, -1\}$ without $r_1'(-1)$ changing.

These four conditions demand the existence of a set of four values

$$\{r_1'(+1), r_1'(-1), r_2'(+1), \text{ and } r_2'(-1)\}$$

and a set of eight values

$$\{\tilde{r}_1'(+1), \tilde{r}_1'(+1), \tilde{r}_1'(-1), \tilde{r}_1'(-1), \tilde{r}_2'(+1), \tilde{r}_2'(+1), \tilde{r}_2'(-1), \tilde{r}_2'(-1)\}$$

such that the following conditions hold:

$$(r_1'(+1), \tilde{r}_2'(+1)) \text{ is poss. if } (x_1, x_2) = (+1 + 1) \tag{8a}$$

$$(r_1'(+1), \tilde{r}_2'(-1)) \text{ is poss. if } (x_1, x_2) = (+1, -1) \tag{8b}$$

$$(r_1'(-1), \tilde{r}_2'(+1)) \text{ is poss. if } (x_1, x_2) = (-1, +1) \tag{8c}$$

$$(r_1'(-1), \tilde{r}_2'(-1)) \text{ is poss. if } (x_1, x_2) = (-1, -1) \tag{8d}$$

$$(\tilde{r}_1'(+1), r_2'(+1)) \text{ is poss. if } (x_1, x_2) = (+1, +1) \tag{8e}$$

$$(\tilde{r}_1'(-1), r_2'(+1)) \text{ is poss. if } (x_1, x_2) = (-1, +1) \tag{8f}$$

$$(\tilde{r}_1'(+1), r_2'(-1)) \text{ is poss. if } (x_1, x_2) = (+1, -1) \tag{8g}$$

$$(\tilde{r}_1'(-1), r_2'(-1)) \text{ is poss. if } (x_1, x_2) = (-1, -1) \tag{8h}$$

where "is poss. if" means that the pair of possible values $(r_1'(+1), \tilde{r}_2'(+1))$ etc. must be compatible with the constraints imposed by quantum theory under the condition that (x_1, x_2) has the value indicated. Each possible value $r_1'(+1)$, etc., is some sequence of n values +1 or -1. The two conditions (8a) and (8b) express the condition (c) that if $x_1 = +1$ then there is some possible value, call it $r_1'(+1)$, of the variable $r_1(+1)$ such that x_2 can, within the structure imposed by the theory, be varied over its domain with the variable $r_1(+1)$ held fixed at the possible value $r_1'(+1)$. The remaining three pairs of equations express the remaining three conditions (a), (b), and (d).

An important distinction must be drawn at this point between satisfying the four conditions (a) through (d) disjunctively, and satisfying them conjunctively. In the disjunctive case the possibilities used to satisfy the four conditions are contradictory possibilities, within the structure imposed by our general theoretical framework, whereas in the conjunctive case these possibilities are noncontradictory, i.e., mutually compatible, within this theoretical structure. It will be argued later that the disjunctive solutions are irrelevant, and may be discarded.

Consider then the two equations (8a) and (8e). These two equations represent two conditions that are to be imposed under the same conditions, namely $(x_1, x_2) = (+1, +1)$.

The values $(r_1'(+1), \bar{r}_2'(+1))$ and $(\bar{r}_1'(+1), r_2'(+1))$ represent two possible values for the outcome of the decision that nature would be forced to make if $(x_1, x_2) = (+1, +1)$. The requirement that these two possibilities be noncontradictory demands that they be the same:

$$(r_1'(+1), \bar{r}_2'(+1)) = (\bar{r}_1'(+1), r_2'(+1)). \tag{9a}$$

One obtains in a similar way

$$(r_1'(+1), \bar{r}_2'(-1)) = (\bar{r}_1'(+1), r_2'(-1)), \tag{9b}$$

$$(r_1'(-1), \bar{r}_2'(+1)) = (\bar{r}_1'(-1), r_2'(+1)), \tag{9c}$$

and

$$(r_1'(-1), \bar{r}_2'(-1)) = (\bar{r}_1'(-1), r_2'(-1)). \tag{9d}$$

These four equations reduce the eight equations(1) to the set of four equations

$$(r_1'(+1), r_2'(+1)) \text{ is poss. if } (x_1, x_2) = (+1, +1) \tag{10a}$$

$$(r_1'(+1), r_2'(-1)) \text{ is poss. if } (x_1, x_2) = (+1, -1) \tag{10b}$$

$$(r_1'(-1), r_2'(+1)) \text{ is poss. if } (x_1, x_2) = (-1, +1) \tag{10c}$$

and

$$(r_1'(-1), r_2'(-1)) \text{ is poss. if } (x_1, x_2) = (-1, -1). \tag{10d}$$

Since quantum theory makes only statistical predictions "everything is possible". However, for any $\delta > 0$, however small, one can make n sufficiently large so that the total probability that $|c - \bar{c}|$ is greater than 10^{-2} is smaller than δ. Thus, by ignoring a set of possibilities whose total probability can be made arbitrarily small by taking n sufficiently large, we can replace the condition "is poss." by "satisfies $|c - \bar{c}| < 10^{-2}$". Then the four conditions (10) on the set $(r_1'(+1), r_1'(-1), r_2'(+1), r_2'(-1))$ become the four conditions that, for each of the four alternative possible values of (x_1, x_2),

$$|c(r_1'(x_1), r_2'(x_2)) - \bar{c}(x_1, x_2)| < 10^{-2}, \tag{11}$$

where $c(r_1, r_2)$ is the correlation function defined earlier, and $\bar{c}(x_1, x_2)$ is the predicted limiting value of $c(r_1, r_2)$ as n tends to infinity under the experimental condition (x_1, x_2). That is, the requirement that the four conditions (a) through (d) be satisfied conjunctively, within the structure imposed by the general theoretical framework, demands the existence of at least one set of possible values $(r_1'(+1), r_1'(-1), r_2'(+1), r_2'(-1))$ such that the four equations (11) can all be satisfied.

For certain arrangements of the experimental parameters the predictions of quantum theory are[14]

$$\bar{c}(+1,+1) = -\frac{1}{\sqrt{2}}, \tag{12a}$$

$$\bar{c}(+1,-1) = -\frac{1}{\sqrt{2}}, \tag{12b}$$

$$\bar{c}(-1,+1) = -1, \tag{12c}$$

and

$$\bar{c}(-1,-1) = 0. \tag{12d}$$

Thus, apart from the one-percent deviations, the four equations (11) give

$$\frac{1}{n}\sum_{i=1}^{n} r'_{1i}(+1)r'_{2i}(+1) = -\frac{1}{\sqrt{2}}, \tag{13a}$$

$$\frac{1}{n}\sum_{i=1}^{n} r'_{1i}(+1)r'_{2i}(-1) = -\frac{1}{\sqrt{2}}, \tag{13b}$$

$$\frac{1}{n}\sum_{i=1}^{n} r'_{1i}(-1)r'_{2i}(+1) = -1, \tag{13c}$$

and

$$\frac{1}{n}\sum_{i=1}^{n} r'_{1i}(-1)r'_{2i}(-1) = 0. \tag{13d}$$

From (13c) one obtains $r'_{1i}(-1), = -r'_{2i}(+1)$, which allows (13d) to be written as

$$\frac{1}{n}\sum_{i=1}^{n} r'_{2i}(+1)r'_{2i}(-1) = 0. \tag{13e}$$

This result, combined with (13a) and (13b), and the fact that each r'_{1i} and r'_{2i} is either plus one or minus one, allows one to write

$$\frac{1}{n}\sum_{i=1}^{n}(\sqrt{2}r'_{1i}(+1) + r'_{2i}(+1) + r'_{2i}(-1))^2 = 2+1+1-2-2+0 = 0. \tag{14}$$

But the fact that each r'_{1i} and r'_{2i} is either $+1$ or -1 also entails that

$$\frac{1}{n}\sum_{i=1}^{n}(\sqrt{2}r'_{1i}(+1) + r'_{2i}(+1) + r'_{2i}(-1))^2 \geq (\sqrt{2}-2)^2. \tag{15}$$

Equations (14) and (15) are contradictory. The small one-percent deviations are not large enough to undo this large contradiction. Thus the four conditions (a) through (d) cannot be satisfied conjunctively.

The logical structure of the argument is this. In nature itself only one of the four values of (x_1, x_2) can be selected. However, our interest is in the structure of adequate

theories and ideas about nature, not nature itself. Quantum theory provides a conjunction of predictions pertaining to alternative possible experimental situations. From the standpoint of theoretical structures both logic and common language provide a basis for contemplating and describing connections between the situations that might prevail under related alternative possible conditions. Classical physics is essentially a compendium of such connections.

The locality principle of Einstein, Podolsky, and Rosen is a theoretical connection of this kind: it says essentially that nothing in R_i can be disturbed or influenced by what the experimenter decides at the last minute to do in $R_j (j \neq i)$. This is a conjunction of conditions, each of which is required to hold only under some condition on the choices of the experimenters. Our criterion for noninfluence converts this locality condition to the requirement that there must be at least one set of possible values for the outcomes of the various decisions that nature could be forced to make such that these possible values are both compatible with the predictions of quantum theory and unaffected by variations in the choice of the experimenter in the other region. However, it has just been demonstrated that there is no set of possible values that satisfy these two conditions.

It is worth emphasizing that the argument does not depend, either explicitly or implicitly, upon the idea that the outcome of nature's decision is predetermined. The whole argument is phrased in a way that tacitly accepts the idea that the outcome of this decision is not predetermined. Nor is there any assumption that the result of any unperformed experiment is physically definite or determinate. For, in the formulation of equations (8), the question is only whether there are any possible values for the outcomes that would allow nature's decisions in each region to remain unaltered as the variable x_i representing the experimenter's choice in the other region is varied. And the conditions (9) merely assert that if two of these possible values represent possible values for the outcome of the same decision then they must, if noncontradictory, be the same. What the actual result "would be" if the experiment were actually performed never enters into the argument: it is neither mentioned, nor represented, nor alluded to. Thus the argument given here avoids the assumption of "counterfactual definiteness" upon which my 1968 and 1971 proofs[13] were explicitly based. The present argument avoids also the assumptions of determinism and hidden-variables present in Bell's original work[9], the hidden-variable factorization property of Clauser and Shimony[12], and the assumption of (microscopic) local realism upon which that hidden-variable factorization property is based. Indeed, in the present approach the entire universe is treated as one giant black box with two inputs representing two tiny elements of freedom in the mental processes of the two experimenters, and two outputs,

which represent the results appearing to the two observers: there is no separation of the world into devices and "quanta". Quanta are never mentioned: the predictions of quantum theory pertaining to what we will see at the macroscopic level are merely accepted as given numbers. Thus there are no ontological assumptions beyond the two general assumptions that the choices of the two experiments can be treated as two free and independent variables, and that two conceivable possible values for the outcome of a single decision by nature are contradictory unless they are equal.

This brings us to the question of the disjunctive solutions of the conditions (a) through (d). These are the solutions in which one or more of the four conditions (9) fail. A failure of any one of these conditions means that the solutions to the four conditions (a) through (d) use, in some instances, contradictory possible values. The problem is to show that such solutions to the set of four conditions (a) through (d) can be ignored, and the necessary condition for noninfluence taken to be the conditions that the four conditions (a) through (d) can be satisfied conjunctively.

Let the four conditions (a) through (d) be called the four conditions C_i. Each condition C_i is a necessary condition for a corresponding property of noninfluence P_i. Each property P_i is of the form: "If the variable x_j has the value x'_j then the choice of the value of the variable $x_k (k \neq j)$ does not influence the outcome of the decision that fixes the value of $r_j(x'_j)$".

Each condition C_i is a necessary condition for the corresponding property P_i. The simple conjunction of the properties C_i is simply the conjunction of necessary conditions for the individual properties P_i to hold separately. This simple conjunction of the properties C_i allows the disjunctive solutions: there is no requirement that the possible values used to satisfy the four different conditions be noncontradictory. But one must distinguish the conjunction of the conditions C_i that the four properties P_i hold separately from the condition, C, that follows from the condition that they hold together.

This condition C can be expected to be stronger than the simple conjunction of the four properties C_i. For example, if P_1 were the property that a set of points S is confined to the X axis then P_1 would imply the condition C_1 that the set S be confined to a set of dimension one. And if P_2 were the property that the set S is confined to the y axis, then P_2 would imply the condition C_2 that the set S be confined to a set of dimension one. But the conjunction of P_1 and P_2 implies the condition, C, that the set S be confined to a set of dimension zero. This condition C is stronger than the conjunction of the two conditions C_1 and C_2.

In our case, the requirement that all four conditions P_i hold does not mean that, for each i, condition P_i holds while others fail. It means that within the theoretical structure under consideration all four P_i hold conjunctively, hence without contradiction. Thus the requirement inherent in the demand that all four conditions P_i hold conjunctively is that all four conditions be imposed together within a realm of noncontradictory possibilities. To show that these four conditions P_i cannot be satisfied within such a realm it is sufficient to show that the four corresponding weaker conditions C_i cannot be satisfied within such a realm. But that is exactly what was shown when it was demonstrated that the four conditions C_i cannot be satisfied conjunctively.

This completes the proof that within the general theoretical framework set up here it is not possible to satisfy together the requirements that, (1), there be no faster-than-light influences and, (2), certain rudimentary two-quanta predictions of quantum theory hold. This theoretical framework is based on two assumptions. The first is that the choices of the two experimenters can, within the present very limited context, be treated as free and independent variables. The second is that two possible values for the outcome of any decision that nature can apparently be forced to make are either equal or contradictory.

The logical foundation for this EPR nonlocality property is the simple mathematical fact, which was proved above, that, for the experiments under consideration here, it is impossible even to conceive or imagine any possible results for the outcomes of the four alternative possible measurements that conform to the predictions of quantum theory, but in which the possible results in each region are unaffected (i.e., unaltered) by variations in <u>what is done</u> in the far-away region.

12. Analysis of a Counterclaim

A recent article[15] contains a purported proof that quantum theory is fully compatible with the demand that there be no faster–than–light influences of any kind:

$$QT \in \mathcal{L}. \tag{11}$$

Here $\mathcal{L}$ is the set of theories that are "fully compatible with the demand that there be no faster–than–light influence of any kind ". What is actually proved in ref. 15 is that quantum theory satisfies a certain "locality condition" that we here call KLC:

$$QT \in \mathcal{K}. \tag{12}$$

Here $\mathcal{K}$ is the set of theories that is consistent with KLC. What is needed to complete the proof of the claimed result (11) from the proved result (12) is that

$$\mathcal{K} \subset \mathcal{L}. \tag{13}$$

But I shall exhibit a model theory MT that is contained in $\mathcal{K}$ but not in $\mathcal{L}$. This shows that KLC is too weak: it does not ensure full compatibility with the demand that there be no faster–than–light influences of any kind.

The condition KLC, restricted to our special situation, is this: for each of the four possible values of the pair (X_1, X_2), and for each pair of values (r_1', r_2') that satisfies the statistical predictions of the theory under the condition that $(M_1(X_1), M_2(X_2))$ is performed, there is some pair of values (r_1'', r_2'') such that: (1), (r_1', r_2'') satisfies the statistical predictions of the theory under the condition that $(M_1(X_1), M_2(-X_2))$ is performed, and, (2), (r_1'', r_2') satisfies the statistical predictions of the theory under the condition that $(M_1(-X_2), M_2(X_2))$ is performed. The conditions for the four possible values of (X_1, X_2) are imposed disjunctively: the values r_1', r_2', r_1'', r_2'' occurring for each of the four alternative possible values of the pair (X_1, X_2) are allowed to be independently chosen quantities. This disjunctive form is to be contrasted with the conjunctive form obtained in section 11.

Let us consider the model theory defined by

$$r_{1i} = \lambda_i \left(\frac{|X_1 + X_2| + (X_1 - X_2)}{2} \right) \tag{14a}$$

$$r_{2i} = \lambda_i \left(\frac{|X_1 + X_2| + |X_1 - X_2|}{2} \right), \tag{14b}$$

where each $\lambda_i = \pm 1$ is a random variable, with probability one-half assigned to each of its two possible values. This model is blatantly nonlocal: the r_{1i} depend on X_2, and the r_{2i} depend on X_1. The observable averages are easily computed. Due to the random variables λ_i the average values of r_1 and r_2 are zero:

$$< \bar{r}_2 > = < \frac{1}{N} \sum_{i=1}^{M} r_{1i} > = 0, \tag{15a}$$

and

$$< \bar{r}_2 > = < \frac{1}{N} \sum_{i=1}^{N} r_{1i} > = 0. \tag{15b}$$

The predicted correlation function $\bar{c}(X_1, X_2)$ is computed from Eq. (1). Its values are

$$\bar{c}(+1, +1) = +1, \tag{16a}$$

$$\bar{c}(+1, -1) = +1, \tag{16b}$$

$$\bar{c}(-1, +1) = -1, \tag{16c}$$

and

$$\bar{c}(-1, -1) = +1. \tag{16d}$$

The nonlocal character of any theory that satisfies (16) is easy to see. Consider first the two equations (16a) and (16c). Under the experimental conditions pertaining to (16a) the results appearing in R_1 and R_2 are perfectly correlated: the value of r_{1i} is always equal to the value of r_{2i}. But under the experimental conditions pertaining to (16c) the results appearing in R_1 and R_2 are perfectly anti–correlated: the value of r_{1i} is always equal to the negative of the value of r_{2i}. If one assumes that the results r_{2i} appearing in R_2 are undisturbed by what is done in R_1 then one can conclude that the two possible measurements in R_1 measure exactly the same thing, apart from a minus sign. That is, the two measurements in R_1 are related in the same way as the measurements performed by two Stern–Gerlach devices that are oriented in exactly opposite directions.

If we could find in nature two different possible measurement procedures that yielded correlation functions of the form (16a) and (16c), respectively, relative to a measurement performed in R_2, and if we could assume that the choice between the two measurement procedures in R_1 necessarily had no effect upon the results r_{2i} appearing in R_2, then we could certainly conclude that the two different possible measurements in R_1 were measuring exactly the same thing, apart from a minus sign.

But let us now change the experiment performed in R_2. Then we find from (16b) and (16d), by means of the same argument as before, that the same two measurement in R_1 are measuring exactly the same thing, <u>with no sign change</u>. Thus the two measurements in R_1 measure either exactly the same thing, or exactly the same thing with a reversed sign. And which of these two cases holds depends upon which experiment is performed in the other region.

This state of affairs is manifestly incompatible with the idea that there are no faster–than–light influences of any kind. Yet it is easy to show that the predictions (15) and (16) entail KLC. For the verify KLC it is sufficient to show that for any set of values r_{1i} satisfying (15a) [resp., values r_{2i} satisfying (15b)] there is some set of values r_{2i} [resp., r_{1i}] that satisfy both (15b) [resp., (15a)] and the appropriate correlation value from (16)] But the two conditions (15) say that the set of r_{1i}'s must be half $+1$'s and half -1's, and that the same is true for the set of r_{2i}'s. But then any correlation in the allowed range $1 \geq \bar{c} \geq -1$ can be readily constructed by making an appropriate matching of the $+1$'s and -1's from the two sets.

It has therefore been shown that (13) is false. Hence the result (11) claimed to be proved in ref. 15 does not follow from the result (12) that is proved there.

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