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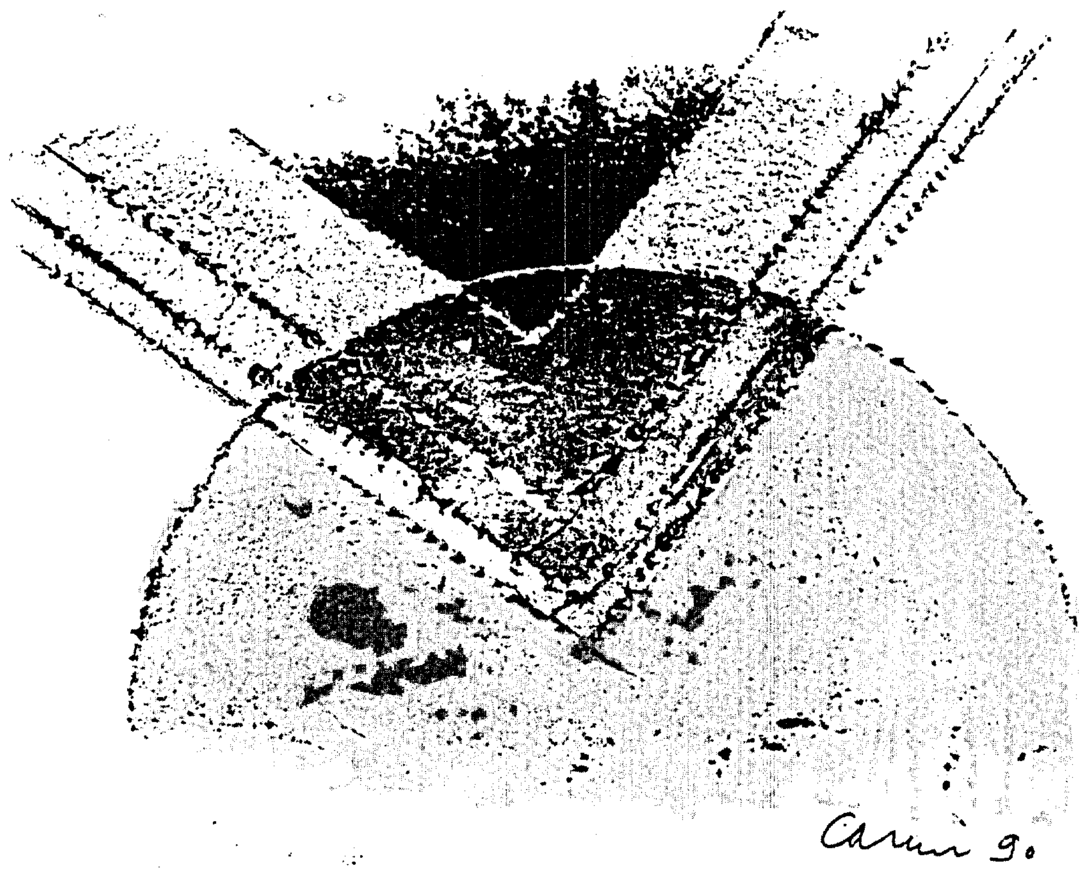

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BELL'S SYMMETRY

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Abstract: *The 'nonlocal connection' between correlated particles, discovered by Bell, is originally asymmetric: Only the first measurement reduces the singlet state. Nevertheless the pertinent correlation, Malus' cosine-square law, is symmetric. All measurements are therefore compatible with the interpretation that the second measurement had been the first even though it was not. This is Bell's symmetry, as noted by Peres. The survival of this symmetry under relativistic conditions is an important, testable question. A positive outcome will imply three novel facts: (i) a reformulation of quantum mechanics is necessary (Park-Margenau axiom); (ii) there exists a Bell connection from the future; and (iii) each of two symmetrically placed mutually receding observers can claim to be privileged (on the nonreduced side). The last point enables a way out of this 'anomalous' situation. Bell's symmetry is analogous to Lorentz's of 1899. In that earlier case too, each observer could claim to be privileged (noncontracted). Einstein discovered the 'covariant' nature of this state of affairs, and Minkowski the implied 'invariant' higher-level description. In the present case, the covariant description exists already (a version of Everett's theory due to Bell). The implied invariant higher-level description has yet to be found. All that can be said already about the latter is that it will be immune from Bell's theorem in the sense that it can be expected to be a local hidden reality. Einstein's rationalism is confirmed.*

1 INTRODUCTION

Finkelstein (1985) recently drew attention to the fact that Bell's (1964) famous result in a sense only 'revives' Malus' result of 1805: The intensity of a light beam which has passed through two consecutive polarisers is proportional to the cosine-square of the relative angle between the two polarisers. This law applies as well to individual photons as is well known. However, surprisingly it also applies when instead of a single photon, *two* photons are used that each pass through a *different*, space-like separated, polariser. The only precondition is that the two photons be correlated (that is, be for example emitted by the sum-spin-zero state of an excited calcium atom). In this case, the very polariser that is used by the first observer could without change of outcome have been *inserted once more* on the other side in front of the polariser used there by the second observer – with the consequence of ordinary Malus behaviour occurring there on the twin photon.

Everyone who for the first time becomes aware of this fact has an eerie feeling of discovery. One senses this when reading the papers of the two discoverers of correlated photons. Wheeler (1946) first predicted correlated photons for the case of a decaying positronium atom (in which case parity calls for the related sine-square law; Feynman et al., 1965). Kocher and Commins (1967) first convincingly demonstrated correlated photons, of the calcium-atom type. They were so baffled that the experiment worked that they forgot to report the results for *all* measured angles, mentioning only those for 0, 45 and 90 degrees (corresponding to correlations of 100, 50 and 0 percent, respectively).

Bell (1964) did not actually describe correlated photons but correlated spin-1/2 particles (in which case the relative angles are twice as large). He nevertheless succeeded in making it clear *why* it is that everyone is baffled, and rightly so. The spin obtained in the first measurement must have been *created* through that very act, and so on both photons. Hence indeed a magic insertion of the polariser used by the first observer, in front of that used by the second, would not change the outcome there. The only alternative conclusion which remains possible is that the very spin forced by the first observer has pre-existed all along on both sides. This assumption is no less unacceptable since it too involves a magic effect.

Bell was able to prove all this with the aid of a syllogism: The assumption that there is *no* magic leads to a contradiction. By assuming what common sense requires – that both particles possess *some* arbitrary correlated spin prior to the first measurement —, he arrived at a formal contradiction with quantum mechanics. This fact is in itself not too surprising since the relevant formula for the singlet state (Bohm, 1951),

$$\Psi = 2^{-1/2}(du - ud) \qquad (1)$$

where the left symbol in each pair refers to the outcome on the left side (*d*, say, for down) and the other to that on the right side (*u*, say, for up), describes a superposition of *two* opposite-spin situations of the very type assumed by Bell only once. Hence Eq. (1) is rotation-symmetric while Bell's assumption is not. However, Bell was able to bring the discrepancy into the form of a quantitative law – a testable inequality. The *invalidity* of this inequality in nature (and hence the validity of quantum mechanics) has since been confirmed abundantly as is well known (see Aspect et al., 1985).

The philosophical importance of the 'connection' discovered by Bell is a matter of continuing debate (cf. Cushing et al., 1989). The world indeed is 'entangled' according to quantum mechanics, as Einstein et al. (1935) had first seen (and doubted) and as Schrödinger (1935) had first demonstrated formally. On the other hand, the very simplicity and specificity of Bell's criterion ("difference between a linear decay and a cosine-square-decay" of correlation as a function of angle in the case of photons of the Kocher-Commins type) has greatly facilitated experimental investigation (Aspect et al., 1985).

In the following, it will be shown that the power of Bell's result is even greater. There exists a *second* implication which may prove no less fruitful than Bell's inequality did. It is a symmetry which too is empirically testable, and which too gives rise to a new picture of reality.

2 BELL'S SYMMETRY

Bell's merit as stated consists in his having looked at *all* relative angles in a painstaking manner. In this way he discovered the new 'Malus law'. The latter, however, like the old one, is *symmetrical*. That is, the correlated outcome is indistinguishable from one which would have been obtained if the first polariser had (by the insertion of a delay loop on that side) been made the second. This is an immediate mathematical consequence of the fact that a cosine-square-law depends only on the absolute value (and not the sign) of the angle.

The fact that the Bell correlations are the same no matter which side reduces the singlet state (so that the same data *could* have been obtained this way or that way) is of importance to experimenters and theorists alike. The former have an easier life this way: They need not bother about whether the emitting calcium atom is in motion or not, nor about which photon was emitted first (since in the calcium cascade - unlike in other devices, see Ou and Mandel, 1988 - , there is a delay of about 5 nanoseconds between emission events; Kocher and Commins, 1967). As to the theorists, Peres (1984) first realized that the symmetry of Bell correlation measurements may render them insensitive to relativistic perturbations. In particular, relativistic observations of Bell's experiment, made in different frames (as first considered by Peres' pupil Susan Feingold in unpublished 1978 notes quoted by Peres, 1984), ought to be equivalent to the standard version.

Recently, the 2-dimensional spacetime diagram drawn by Peres (1984) was rediscovered ('VX-diagram', with the letter X on top of the letter V; Rössler, 1990a) and given a new meaning. This situation (light cone crossed by two mutually slanted frames) can be implemented in a 'direct' experiment - by using two mutually receding measuring stations including observes, one in each frame. At the same time the experiment is feasible with modern technology if one of the two measuring stations is put into an orbiting satellite (Rössler, 1990a).

The survival of Bell's symmetry under relativistic conditions is, therefore, testable to date. This 'well-posedness' of Bell's symmetry justifies a closer look at its implications.

3 'NEGATIVE IMPLICATIONS' OF BELL'S SYMMETRY

If Bell's symmetry persists under the 'critical' condition that in *either* frame, the singlet state is reduced by the frame-specific measurement (Rössler, 1990a), a change in the standard formalism of quantum mechanics is called for. In particular, an old claim made by Einstein, Podolsky and Rosen (1935) - that quantum mechanics "can be completed" in the sense that more than one noncommuting reality can be accessed by means of one's making a proper use of relativity — is vindicated.

This is unexpected since EPR were successfully shown to be mistaken on the issue of entanglement by Bell (1964) as is well known. How could they then still be right on the issue of completability, which they themselves had *linked* to the issue of entanglement? The resolution lies in the fact that this link is accidental and unnecessary while the main argument survives.

More specifically, Einstein's only mistake consisted in the fact that he thought that relativistic insulation (space-like separation) *suffices* in order to effectively 'decouple' two correlated particles. This is not the case as Bell (1964) showed. The remaining argument was *not* flawed, however: The decoupling (once accomplished) should allow two noncommuting measurement results (like the two projections s_{1y}, s_{2y} and s_{1z}, s_{2z} of the $S^2 = 0$ state of the emitting calcium atom) to be ascertained with impunity each, one on the left particle – s_{1y}, say – and the other on the right particle – s_{2z}, say – , so that a 'more complete' description of the world than quantum mechanics permits becomes possible. It is only because of— the fact that under a condition of mere space-like separation, a unilateral measurement immediately throws the other particle into the corresponding eigenstate at a distance, that the latter particle is no longer available for an independent second measurement. Hence the commutation relations are indeed *not* put in jeopardy as Bell showed (cf. 1971).

Relativistic insulation as proposed by EPR is, however, not the *only* means to 'causally decouple' two particles. Relativistic time-order inversion is waiting in line as a more efficient second alternative. Indeed, the former method (space-like separation) does not even qualify as a fully relativistic feature since it requires both measurements to be carried out in one and the same frame. *All* EPR experiments carried out so far have respected this restriction. Nevertheless this restriction represents but a singular (zero-measure) subcase. Even an infinitesimal relative speed between the two measuring stations suffices to remove it. Formally, EPR's argument breaks down in this case because they never mentioned relativistic time-order inversion as a potential alternative method. In spirit, however, their argument clearly survives.

The fact that EPR never mentioned the alternative is, moreover, understandable. It would have been confusing to alert the reader to the more general possibility in the absence of any evidence that the more restricted one should fail. For there existed no reason for Einstein to believe in the existence of entanglement (and hence the potential failure of mere space-like separation) in the first place. Not even Schrödinger did. When Schrödinger, later in the same year, first coined the word and worked out the formalism of 'entanglement' (Schrödinger, 1935), he did so exclusively in order to expose an unacceptable new feature of quantum mechanics – so that it might be rectified in the near future. Bell's success proved both Einstein and Schrödinger wrong, not with their joint discovery that quantum mechanics is entangled, but with their shared belief that nature most certainly will *not* comply. Bell provided the means by which the opposite fact could be demonstrated empirically – although he at first also expected the outcome to favour his own inequality (Bell, 1971).

Finally, Bell's cosine-square law will most probably *survive* the transition toward a relativistic situation in which the two measuring apparatuses are no longer confined to the same frame. For since the second particle's spin is fixed after the first measurement, in the frame of the first measurement, this fixed spin can as well be ascertained by means of a moving — receding — measuring device without change of outcome. Therefore the second measurement, carried out in the other frame, is perfectly acceptable in the frame of the first measurement. This result, which for infinitesimal velocities is valid for all particle types, remains true for photons up to arbitrary relativistic velocities of the second measuring device since photons possess no forward spin (Bjorken and Drell, 1964).

One thing does break down in the transition from zero relative speed to an infinitesimal one, however. It is the *linkage* between nonlocality on the one hand and uncompletability on the other. This linkage is (as implicitly noted by Bell, 1971) valid only as long as the two frames are characterized by the same ordering in time as far as the two measurements are concerned. There does, nevertheless, always exist a finite 'window' of configurations in which *either* receding measurement is second in the frame of the other. Finding this window experimentally is not completely trivial since for small enough relative speeds, even the spatial extension of the measuring apparatus suffices to obliterate it; moreover, the window ceases to exist altogether below a certain finite threshold due to the 'temporal width' (an intrinsic delay of the order of one nanosecond) that is characteristic of modern photon detectors. Both constraints taken together make it necessary to turn to fairly 'high' (from the point of view of earth-bound transportation) relative speeds. Nevertheless the required velocities clearly remain 'nonrelativistic' ($v/c < 10^{-4}$), so that the experiment is indeed feasible (Rössler, 1990a).

Surprisingly, however, what one thereby obtains free of charge is *two* experiments, each with its own Bell connection, in *one*. For in each of the two inertial frames, a photon with a well-defined spin has been generated by the stationary (in that frame) measuring apparatus, before that photon is going to impinge on the receding measuring device used over there in the other frame. *Either* of these two cases is perfectly standard, that is, is *identical* to a classic Bell experiment (since a receding measuring device is perfectly acceptable for photons as we saw). Hence in *either* frame, the outcome to be obtained on the other side – provided a matching direction of measurement is chosen there – "can be predicted with certainty".

This is the decisive phrase from EPR's paper (Einstein et al., 1935). Admittedly, this prediction remains counterfactual in the sense of Stapp (1972) if the other side chooses to measure a completely unrelated (fully noncommuting, 45-degree) angle. However, it is correct to say that under this very condition it *is* possible to ascertain two noncommuting quantum states on the emitting object (Einstein et al., 1935). Moreover, counterfactuality need not even be invoked since quantum mechanics is already opposed to one's obtaining a second projection that is but partially noncommuting (corresponding to angles close to but not equal to 45 degrees). Bell's symmetry, if thus confirmed relativistically, proves EPR right, *both* for the fully noncommuting (45-degree) angle of Kocher and Commins (1967) *and* for all neighbouring (Bell, 1964) angles for which counterfactuality is no longer a problem.

The relativistic Bell experiment can, therefore, be said to constitute an 'improved version' to EPR's original proposal. Surprisingly, nonlocality *refuses* to interfere with relativity's power to 'Einstein-complete' quantum mechanics.

4 A DIRECT CONSEQUENCE

The preceding 'negative' result (that EPR were *not* wrong with their main argument) directly entails an implication which was first worked out by Park and Margenau (1971). These authors, after independently rearriving at EPR's experiment and Bell's experiment (Kocher-Commins angles), already saw that the commutation relations can be violated thereby (although the above relativistic argument was not yet available). They accordingly sought a 'maximally conservative' reformulation of quantum mechanics which takes this new fact into account. They found that it suffices to slightly alter *one* of Von Neumann's axioms (the correspondence between linear Hermitian operators on Hilbert space having complete orthonormal sets of eigenvectors on the one hand and physical observables on the other). This 'strong' correspondence (bijection) only needs to be replaced by 'weak correspondence' (injection) as Park and Margenau (1971) were able to show.

This modification, even though minor, would be the first amendment of quantum mechanics ever. It apparently is unavoidable if the relativistic Bell experiment works. In this anomalous situation, it is perhaps of interest that an – on the face of it – even more innocuous way of responding to EPR's final success can be indicated. In a first step, one asserts that quantum mechanics can stay as it is since Bell's nonrelativistic theory remains applicable in either frame (only *later* does an incompatible interpretation arise as allegedly valid in the other frame). In a second step, one acknowledges that the experiment provides empirical support for Heisenberg's well-known claim (Heisenberg, 1929) that the commutation relations – which he had discovered – *can* be violated *in retrospect*, but not in prospect. To accept this latter claim seems to amount to a very modest change of formalism indeed.

However, even this 'minimum' change ceases to be marginal if a closely linked second point is taken into regard. As soon as one takes the Bell correlations seriously (as representing a connection of some sort), the 'future' – the other observer's actions – is as much involved in shaping each observer's measured outcome as his or her own decisions are. Indeed, a 'counterfactual telegraph' (Rössler, 1990b) can be built on this basis, in a bilateral fashion, with 'messages' that can be deciphered only after the second 'half-message' has arrived too along conventional channels. Such interpretations can be upheld as long as no local explanation of the Bell correlations (cf. Hoffmann's, 1988, 'discrete-indeterministic' proposal) has been found. They acquire an unacceptable ring if Heisenberg's hypothesis is accepted.

The present 'doubly' anomalous situation (coexistence of noncommuting quantum states; connection from the future) unexpectedly represents an accepted staple of current physical thought – only an *example* simple enough to be amenable to empirical scrutiny (Rössler, 1990a) appears to have been lacking up. Indeed, relativistic quantum mechanics (including relativistic quantum field theories) implies that it is 'legal' to apply different sequential orderings (space-like hypersurfaces) to the same measured results in spacetime (Landau and Peierls, 1931; Bloch; 1967, Schlieder, 1968; Hellwig and Kraus, 1970; Aharonov and Albert, 1984). Therefore, two noncommuting quantum states can actually be assigned to the excited sum-spin-zero state of the emitting calcium atom, not only 'in retrospect' as pondered above, but in spacetime, that is, objectively.

More technically speaking, the notion of a (single) quantum state needs to be abandoned in relativistic quantum theories because it is not Lorentz covariant (Aharonov and Albert, 1984). In its place, a 'functional' of such states (that is, a multitude), taken over all possible frames, needs to be adopted for every point in spacetime (Aharonov and albert, 1984). In this way, Einstein et al.'s (1935) controversial prediction that relativity implies a refutation of the universal validity of the commutation relations is reproduced today as a matter of course in relativistic quantum theory (although the connection to EPR is usually *not* drawn; Meier, 1990). In the same vein, the second anomalous conclusion mentioned above (connection from the future) also is an element of the modern 'absolute universe' of relativistic quantum theories. Indeed, *any* invariant theory of space-time which contains the Bell correlations as an ingredient is necessarily 'bilaterally Bell-connected' by definition. This consensus goes so far that the concept of an invariant (if multiple-state) relativistic world would break down if the Bell correlations turned out in the relativistic Bell experiment *not* to possess the symmetry properties discussed above. When looked at from this vantage point, Bell's symmetry is indeed so natural as to border on the trivial.

5 'POSITIVE IMPLICATIONS' OF BELL'S SYMMETRY

The above 'negative' implications of Bell's symmetry were all standard in spite of their being partly controversial from the point of view of nonrelativistic quantum mechanics. When they are adopted, the usual picture of the world – a relativistic absolute world in the spirit of Bohr's (if partially non-unique) – can be upheld.

The 'positive' implications, to be considered next, are nonstandard by comparison. On the one hand, they lead to a radically different picture of the world; on the other, their derivation is based on a formal argument which if you wish is 'only aesthetic'. It reads: Bell's symmetry is 'too symmetric' because it implies that each observer can rightly claim that to be privileged over the other.

On first glance, such a symmetrically privileged state of affairs appears entirely acceptable. There never arises any inconsistency between the empirical data on the one hand and the adopted theory on the other. *Both* versions of the theory, the one valid in the one frame and the other valid in the other frame, are *equally* capable of explaining the observed correlations. The problem is only that these two (under an exchange symmetry identical) theories *contradict each other*. Since this inconsistency is of an 'intra-theoretical' kind, one may still be inclined to call it 'weak.'

However, there never exists any hint in nature that is more powerful than a perfect symmetry. Here, we do have a perfect symmetry. Therefore, the question arises whether what at first sight only represents a puzzle may not actually constitute a *lever* which when properly exploited might force everything onto a new level of higher consistency.

While this possibility cannot be ruled out a priori, the hope that it can be implemented today sounds a bit like wishful thinking. Fortunately, however, there is a narrow avenue left along which progress appears possible. It consists in one's turning to historical precedent for guidance. Any approach by analogy can of course only be used heuristically, that is, every single step needs to be checked independently.

The historical precedent is *Lorentz's symmetry* of almost a century ago. In that earlier case, it also was the negative outcome of an experiment (Michelson and Morley, 1887) which needed to be accommodated by theory. Fitzgerald's famous 'contraction hypothesis' (Fitzgerald, 1892) enabled the accepted absolute description of the world of his day to survive. The state of 'absolute velocity' of any subsystem would determine its degree of absolute contraction in space (and time; see Lorentz, 1899). The invariant description thereby arrived at was no longer unique, however. There existed *other* ways to explain the same data, that were equally valid implementations of the same theory despite the fact that they contradicted each other individually. In particular, the observer was free to assume that the contraction law applied to all objects as a function of their velocity relative to himself (since the speed of light appeared to be kept constant just for him). Therefore, *each observer could rightly claim to be privileged over the other.*

6 'BELL COVARIANCE' ANALOGOUS TO 'LORENTZ COVARIANCE'

The solution was found by Einstein (Einstein, 1905): It suffices to render the excess symmetry *explicit* in order to exorcise it like a bad demon. A description of the world is then arrived at in which the *laws* of the world, as valid for each observer, are the *same*. This so-called 'covariant' (Minkowski, 1908) description of the world frees each observer from his privileged position by giving the other the same rights in a *non*contradictory manner. The price to pay was that, while the laws of nature become noncontradictory, the *facts* of nature (the results of observation) became noninvariant. Mass, length, duration, simultaneity etc. all cease to be invariants of measurement. Indeed, the whole previously existing invariant world of objective type disappears while at the same time a new invariant 'absolute world' (Minkowski, 1908) makes its entry. The latter, however, is of a radically different kind; it is invariant at the expense of being no longer tangible. What remains tangible is only the 'cuts' (the observable worlds) of equal rights that can be run through it. Taken as a whole, the invariant world is no longer coextensive with the world as it is observed. Since every cut yields a different manifest world, 'most' of the absolute world's properties are no longer reflected in any particular cut – they are hidden. As a *hidden world*, the absolute world ceases to qualify as a 'direct' description of the world. It only is a 'meta-description'.

The above new example of observer-privilege clearly is amenable to the same solution. The *contradiction* between the two symmetric 'explanations' that are given by the two mutually receding observers to a pair of quantum observations can be made go away if one opts for taking the symmetry seriously. The *laws* then become equal in a noncontradictory ('covariant') fashion while the *facts* become noninvariant.

From a formal point of view, this proposal is perfectly acceptable. The formalism of nonrelativistic quantum mechanics can be *retained* by each observer — just as, in the previous case, each observer could stick to his own 'privileged' Lorentzian way of describing the world. At the same time, what formerly was coextensive with the only absolute reality acquires the status of a mere 'cut'. The two cuts, however, are *no longer the same* by definition.

The last-made statement is surprising. In the previous case, the two observer-specific cuts ('frames') *also* turned out to be different; but in that case, the presence of *some* differences existing between the two was known from the beginning. In the present case in contrast, the two observer-specific cuts ('worlds') are *not* recognizably different. The one observer makes the one measurement and communicates it to the other, and vice versa. Thus, both clearly share the same data. Therefore it comes as a major surprise that Einstein's trade-off principle between laws and facts, when applied to the present case, implies that the data must *not* be the same even though they *are* the same.

Nevertheless there is no mistake involved. *If* Bell-symmetric quantum mechanics is elevated to the rank of a covariant theory (so that its laws are valid on either side in a noncontradictory manner), then the above paradoxical implication appears unavoidable. Recall that on each side, the laws of nonrelativistic quantum mechanics imply that the one measurement result is an eigenstate obtained directly from the superposition-type singlet state of the emitting calcium atom as a reducing projection, and that the other is *not*. Even though it is correct to say that each pair of results *could* have come out the same way if instead of the one set of laws the other were applicable (Peres, 1984), it also is correct to say that this statistical (with a certain probability admissible) equality must not be valid in *every* individual case. The two quantum worlds cannot be identically the same each time without the laws of each being violated. Conversely, if such a violation is to be axiomatically excluded in the spirit of Einstein as shown, then the two quantum worlds which are valid for the two observers cannot be equal in a fact-wise manner every time – despite the fact that each contains the other observer and his data.

This means that just as the notion of 'Lorentz covariance' implied the existence of more than one inertial *frame*, so the notion of 'Bell covariance' implies the existence of more than one quantum *world*.

7 THE DRAWBACK OF COUNTERFACTUALITY

The new result – existence of more than one quantum world – suffers from a drawback. It by definition is impossible to verify directly. While the different frames of relativistic covariance can communicate with each other (and thereby confirm the fact-wise discrepancies), the different worlds of Bell covariance are mutually *opaque* by definition. That is, the other observer complies in the world of each.

Indirect verification nevertheless remains an option. One possibility is experiment. Deutsch (1986) proposed an experiment for the not too distant future in which a quantum decision is later 'undone' again while simultaneously some 'meta-information' (about the fact that it had occurred at all) is retained. Such a meta-distinction is crucial also in the counterfactual telegraph that was mentioned above ('occurrence' vs. 'nonoccurrence' of interference in an optical Wigner circuit; Rössler, 1990b). The counter-factual telegraph can in principle be combined with Deutsch's proposal. Three possible experimental outcomes are envisionable: (a) The combined experiment works *so* well that the counterfactual telegraph is turned into an actual one in violation of Eberhard's theorem (Eberhard, 1978) and, therefore, Einstein causality. Since this violation could only be unidirectional, the fact-wise asymmetry of Bell covariance would thereby become manifest. (b) The telegraph remains counterfactual while *some* additional information (meta-information) remains accessible. (c) Meta-information of the type sought by Deutsch cannot be obtained.

Other, less exotic, experimental proposals may be envisionable as well. However, there is perhaps no need to verify Bell covariance as such. The associated 'higher-level invariance' (cf. Section 9) may prove amenable to verification instead. Note that in the case of relativity, it too was this 'third' method (to predict the features of a frame from the invariant Minkowskian picture) which proved more important than both the 'direct' method (to communicate) which is here blocked and the 'indirect' method just discussed.

The second option is to go back to theory one more time.

8 BELL COVARIANCE IS IMPLICIT IN EVERETT'S THEORY

Bell covariance is tantamount to the existence of more than one 'quantum world' (one for each frame) as we saw. More than one quantum world – in fact, many – are implicit also in Everett's (1957) version of quantum mechanics as is well known. Is there a relation? Unlike Everett's theory which is considered 'empirically equivalent' to all other admissible versions of quantum mechanics (like Bohr's), Bell covariance is motivated by empirical observation. Hence the question of whether there exists a version of Everett's theory which reproduces the above finding is a nontrivial one. For latter version of quantum mechanics would then be empirically favoured.

An appropriate version of the Everett formalism indeed exists. The prototype has (not coincidentally perhaps) been discovered by Bell (1981); cf. also Healey (1989) for a related proposal. Bell pointed out that the many worlds ('branches') assumed in Everett's picture, one for every quantum decision achieved, *need not* be postulated to exist along an 'unphysical' new dimension (as is ordinarily assumed). Rather, it is possible to arrive at a *single* world again if the unphysical new dimension is replaced by the *time* axis. All the mutually insulated quantum worlds – each with its own consistent past (Everett, 1957) – then no longer exist simultaneously, but rather sequentially. The fact that the 'residence time' of each world during which it is valid along with its implied past is necessarily very short (in fact, almost infinitesimal) is 'screened' from the observer no less efficiently than the different worlds (branches) are screened from each other in Everett's standard version. The origin of the opacity lies in the fact that whenever a whole world has been replaced by another, the latter by definition contains no trace of the former. Hence the change-over must be imperceptible, too.

Bell's interpretation, while at first sight appalling, is appealing from a philosophical point of view. For the first time, a piece of physical evidence has been unearthed (if only in the form of an hypothesis) which supports the fundamental phenomenological fact that to a human observer, the world is new at every moment. Both the past and the future are only given to us in the form of the now (Augustine, 395). But even from the point of view of science, Bell's courageous idea must be considered progress. Whereas previously, *two* independent foliations, each of codimension one (a point on a line) had to be postulated – namely, Everett's and Augestine's –, now a single one potentially also of codimension one (a point in a fractal curve) suffices. The arbitrariness of the now and the arbitrariness of the quantum world become linked together. This unification opens up the prospect that a common explanation may be found eventually.

In the present context, all that is stake is a confirmation of Bell's proposal. At first sight, an obstacle lies in the fact that Bell strove for obtaining uniqueness again while in the present context, the existence of *more than one* quantum world needs to be explained. It turns out, however, that the reduction achieved by Bell actually stops short of uniqueness. Since the foliation of nows was included in the picture, the uniqueness arrived at is valid only for the individual observer for whom nowness is a phenomenological reality. *Two* observers, while both represented within the unique world valid for each at that moment, nevertheless *need not* live in a pair of identical now-worlds. In fact, they almost never do.

The fact that nowness is unconfirmable is known in modern philosophy on the basis of rather deep ethical arguments (Levinas, 1946). In physics, it follows directly from Einstein's discovery of the nonuniqueness of simultaneity (Einstein, 1905). Two observers *cannot* in general live in the same now-world (unless their velocities are infinitesimally close at every moment) as Gödel (1949) saw. This result when contemplated in the context of relativity alone makes little difference since spacetime is invariant anyhow – so that only minor shifts in subjective synchronization appear to be at stake. In the present hybrid (relativistic-plus-quantum) context, however, the smallest finite difference suffices to *split* the world. Two now-worlds therefore cannot assumed to be equal.

It follows that at every moment, a different quantum world is in charge, not only for each observer taken alone (as found by Bell (Bell, 1981)), but also across observers. *Both* facts are screened from the observer. The near-infinite multiplication of worlds implicit in Everett's picture thus has given way to finite multiplication – across observers.

However, the '*n*-fold' covariance (observer-covariance) thereby arrived at is still different from the merely 'two-fold' covariance (Bell covariance) which is needed in the present context. However, the requisite reduction in multiplicity (down from *n* to *2*) *is* already implicit in the notion of observer-covariance itself. The latter not only contains Bell's 'unique' version of Everett's theory as a special case as we saw, but also the 'bi-unique' version required here: Always as many observer-specific worlds can be 'lumped together' into one as the evidence permits. In the light of Bell covariance, a single equivalence class is no longer sufficient but two are. Hence we are finished. Everett's version of quantum mechanics is compatible with Bell's symmetry, while Bohr's is not.

The chain of implications so far arrived at can be summarized as follows: *Empiry* (yet to be confirmed) *implies Bell's symmetry implies Bell covariance implies (Bell-)Everett version of quantum mechanics.*

9 BELL COVARIANCE THROWS NEW LIGHT ON BELL'S THEOREM

There is one remaining implication of the new multiplication of worlds to consider: The new *co*variance is by definition imbedded in a new *in*variance. By their being nothing but cuts, the new 'worlds' call for the existence of an invariant 'hyperworld' in the same way as relativity's new 'frames' called for the existence of an invariant 'hyperframe' (Minkowski's absolute world).

The new invariant hyperworld ('totality') has yet to be formulated. This aim may or may not be achievable in the forseeable future. Even more important than the question of explicit constructibility in the future, however, is the question of whether or not certain *features* of the hyperworld can already be indicated today. A particularly important question is: must the hyperworld be both *acausal* and *nonlocal* in harmony with the worlds that it gives rise to?

Both subquestions can already be answered – in the *negative*. Bohm (1952) as is well known described a first hidden-variables theory of quantum mechanics which, unlike quantum mechanics itself, is *causal*. Therefore, the possibility that an explicit version of the present hidden hyperworld may be found in the future that is causal too cannot be ruled out.

The second prediction – nonlocality – appears less doubtful at first sight. Bell (1964) as is well known demonstrated that any hidden-variables theory which is causal (like Bohm's) must still be as nonlocal as quantum mechanics itself is. The present hidden hyperworld *is* a hidden-variables theory of potentially causal type. It therefore appears to be bound by the nonlocality constraint at least in case it is causal.

This conclusion presupposes, however, that no sufficiently fundamental *difference* exists between the present hidden world on the one hand and Bohm's class of hidden variables on the other. If we leave aside the fact that Bohm's theory is a shining edifice while the present result is unfinished, two major differences come to mind: 1) Bohm's world is empirically equivalent to non-relativistic quantum mechanics, while the present hyperworld is called for by relativistic observation. 2) The present hyperworld, unlike Bohm's world, is of an 'indirect' kind. It is the latter difference which suffices to invalidate the prediction of nonlocality.

Giving rise to more than one quantum world, the present hyperworld by definition no longer directly reflects the properties of each cut (since the cuts contradict each other in a fact-wise manner). Note that Minkowski's absolute world, in spite of its giving rise to the empirical property of *contraction* in every cut in a different way, nevertheless is *not* subject to contradiction itself. Similarly the present absolute totality, in spite of its giving rise to the property of *nonlocality* in every cut in a different way, nevertheless is not bound by nonlocality itself. More specifically, the nonunique relationship that exists between the present hidden-variables theory and the quantum reality violates a uniqueness assumption (between hidden parameters and reality) made explicitely by Bell (1964) in deriving his theorem.

A more 'positive' demonstration of the same fact (that the hyperworld may be local) is possible in the context of the observer-covariant version of Everett's theory of the preceding Section. There, the observed nonlocal correlations were observer-specific (world-specific) by definition. This makes it possible in principle to include *relations* between the individual observer and his cut, in an attempted explanation of nonlocality. Relations as is well known can be instantaneous (nonlocal) *without* any connection at a distance being thereby implied. The fact that the nonlocality exists only in the world of the observer (who is reached by both measurement results in a subluminal fashion) makes it possible to include the observer in the explanation of nonlocality. It follows that not just the present, but *any* 'observer-centered' theory of quantum mechanics is immune from Bell's theorem. A case in point is Everett's theory itself (Rössler, 1990c). Similar conclusions were recently reached by Christiansen (1990) and De Baere (1990).

To the chain of implications of Bell's symmetry presented at the end of preceding Section, there can thus be added a last element: ... *implies immunity from Bell's theorem.*

10 DISCUSSION

Two simple laws – Bell's cosine-square law and Einstein's VX diagram (light cone crossed by two slanted frames of observation) – were put together to see how they match. For the experiment is feasible (Rössler, 1990a). Only the conceptual implications were focused on since a more technical paper covering almost the same ground in a masterly fashion is available (see Peres, 1984).

The *first* part of the present paper dealt only with facts that are in principle well known (although a simple example amenable to empirical scrutiny appears to have been lacking before). The two 'new' facts described – that *both* relativity and quantum mechanics cease to be literally valid in view of Bell's symmetry – were, therefore, less surprising than meets the eye. Peres (1984) carefully avoided any dramatization of the situation. The absolute relativistic quantum universe in the spirit of Bohr is indeed not endangered – if more than one quantum state per spacetime point is put up with.

The *second* part of the present paper was devoted to a 'third' implication of Bell's symmetry which appears to have gone unnoticed previously. The symmetry is 'too perfect' to be accepted at face value. If one takes this hint seriously, three surprising implications emerge: (1) The already accepted two 'improvements' in the two most basic theories of physics can be dropped again. (2) A previously 'undecidable' competing theory to Bohr's gets confirmed (Everett's). (3) A new absolute reality exists which is no longer of the 'direct' type.

On the way toward point (2) three apparently new facets concerning Everett's theory could be seen: Everett's theory is (a) observer-covariant, (b) immune from Bell's theorem, and (c) close to providing an explanation of nowness. The third feature has already been glimpsed by Deutsch (1986).

Point (3), finally, is related to Bohm's concept of 'implicate order' (Bohm, 1980). The latter consists in a nonlocal 'holomovement' whose relation to the observer is a "very subtle question" (Bohm, 1984). In contrast to Bohm's by definition 'unverifiable' holistic view of nonlocal types, however, here the unexpected prospect arises that the 'totality' may be both local and accessible.

To conclude, the empirically decidable 'bilateral' Bell connection possesses implications which go beyond those of the classic unilateral case. Specifically, (i) quantum mechanics can be completed, (ii) the future can affect the present, and (iii) a 'weak' inconsistency is part of the accepted formalism. All three implications taken together amount to a 'cloud' on the horizon of the next century. On the other hand, one's focusing on point (iii) alone suffices to 'lift' the cloud if a formal device used only once before is adopted. The 'covariance' proposal has the additional consequence that it selectively confirms one particular version of quantum mechanics (Everett's). Finally, at a higher-level 'totality' must exist in confirmation of classical physical rationalism. Bell, in correcting an oversight of Einstein, exposed a new symmetry of Einstein's type.

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