Non locality: Mystery or Myth?*

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A survey of a study leading to the conclusion that there is no support for non locality in Quantum Mechanics is presented. Models based on Malus' Law for generic EPR and GHZ experiments are cited. It is observed that 'entangled' polarization, as governed by the $SU(2)$ group structure, cannot be a quantum phenomenon. The implications of these results for researches on quantum computing are considered.

I. THE PROBLEM: CONTRADICTION!

Perhaps the most alarming deduction from twentieth century Physics is the crass contradiction between its two most successful theories. On the one hand, EINSTEIN's theories of relativity essentially preclude superluminal velocities as physically impossible; and both are so well verified by observations, that it seems incontestable that whatever deficiencies or defects they still have, must be marginal,.

On the other hand, the current interpretation of Quantum Mechanics seems to imply that there is nevertheless a kind of interaction that transpires superluminally. This special interaction arises in connection with the wave collapse of correlated pairs of particles.

There is, of course, a popular rationalization for this conflict. It is based on the observation that the type of interaction involved in quantum wave collapse cannot be used to communicate superluminally. This argument, however, does not conform with the "speed limit" from Special Relativity, which precludes "interaction," not "communication." The issue is not whether observers of the effect can manipulate it for applications, but whether there is any kind of superluminal "interaction" in nature, exploitable or not.

In the end, this conflict cries out for resolution.

One option would be that it does not exist, that an error has led only to the appearance of conflict. In fact, this is the conclusion of this writer. He was brought to this opinion by the observation that wave collapse itself is not an integral element of Quantum Mechanics; it does not conform to Schrödinger's Equation, which is one way or another closely related to the empirical support for that theory. The hypothesis pertaining to such 'wave collapse,' is actually a rescue attempt for otherwise mysterious prescriptions for interpreting wave functions.

As is very well known, this matter attracted interest very early in the history of Quantum Mechanics. Von Neumann appears to have been the first to consider the issue when he presented an argument to the effect, that the probabilistic nature of wave functions invested in them by Born, could not be removed by 'completing' Quantum Mechanics by extending the theory with additional, so far 'hidden,' variables. Thereafter, John Bell reanalyzed his argument, discovered an inappropriate hypothetical input in it, and proceeded to develop his own argument on the possibility of the existence of a hidden variable extension. Although Bell's professed hope was to show that in fact such variables could be found, his own considerations, motivated by the intention to find an empirically testable formulation, surprised him by leading to the conclusion that, if such variables were introduced, they would then also introduce non local interaction. His proposal in this regard has been dubbed a "theorem," and thereafter generally taken very seriously and presumed correct.

However, Bell is no more immune than von Neumann to the consequences of covert hypotheses; and, indeed, such have been found in his arguments, first by Jaynes in 1988.

II. ERRATUM

Motivated by the arguments from Einstein, Rosen and Podolsky (EPR), Bell, famously, based on the rendition of EPR's counterexample showing the incompleteness of Quantum Mechanics as modified by Bohm, developed a statistic, which if not satisfied by data from EPR-B experiments, is supposed to show indeed that both nature exhibits nonlocal determination of correlations, and that QM cannot be 'completed' without it.

The basic setup of the experiment is as follows: a parametric down conversion crystal generates a pair of pulses with, say, anticorrelated polarization states. It is taken, according to the precepts of QM, that this pair forms a singlet state for which neither daughter pulse has a specific polarization until it is "collapsed" by a measurement. Then, to conserve total angular momentum, the sibling pulse must collapse 'at-a-distance' immediately to the anticorrelated state of polarization.

Bell proposed that the coincidence probability, $P(a,b)$ of a measurement of the left pulse having polarization in state a together with the right pulse in state b, should satisfy the equation

$$P(a,b) = \int A(a,\lambda)B(b,\lambda)\rho(\lambda)d\lambda, \tag{1}$$

where $A(a,\lambda)$ and $B(b,\lambda)$ are the expectation functions of a 'hit' or a positive measurement at station A when its polarizer has setting a, and B has setting b; λ are symbols for purported hidden variables which determine the precise state of the pulse, and $\rho(\lambda)$ is the distribution of such variables.(1)

Now it is exactly at this point where the crucial step made by Bell enters the logic of his argument: he supposes that

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*Presented at: International Conference: Quantum Information-2007; Moscow-Zvenigorod, 1-5 Oct. 2007.

the fact that any setting of a measurement device at station B, namely b, cannot have a nonlocal effect at station A. In other words, he concludes that the expectation function for measurements at station A cannot contain as an argument the symbol b. Likewise, B cannot contain a. In this way he justifies Eq. (1), which then becomes the basis of a derivation for an inequality involving the data from an EPR-B experiment which should hold true under these assumptions. Observations show that the derived inequality is violated; and, this is said to show that the assumption of only local interaction (in this case the determination of correlations) is invalid.

Bell's supposition and justification are not generally valid, however. To see this it is vital to fathom exactly the meaning of the expectation functions A and B. An expectation function, when integrated over its whole domain, i.e., $\int A(a,\lambda)\rho(\lambda)d\lambda$, gives an 'expectation value,' or average; it has the generic form $\lambda P(\lambda)$ where $P(\lambda)$ is the probability of the occurrence for the variable λ. In this generic form one sees immediately that the general form for correlated events, which the joint probability must conform to, is what is called Bayes' Law (or the definition of a *conditional* probability), namely:

$$P(a,b) = P(a|b)P(b), \tag{2}$$

where $P(a|b)$ is a *conditional* probability. Such a conditional probability differs from a pure probability whenever the two joint events are correlated. When these considerations are made, then Bell's supposition , Eq. (1), takes the form

$$P(a,b) = \int A(a|b,\lambda)B(b|\lambda)\rho(\lambda)d\lambda. \tag{3}$$

With this form for $P(a,b)$, the derivation of Bell inequalities is stymied; by proceeding anyway, one therefore injects the implicit assumption, that the joint events are uncorrelated. Testing them with correlated events, then, yields incoherent results.

Some proponents of Bell's analysis do not accept this criticism on the grounds that the explicit variables in Eq. (1) giving the settings for the measuring devices, must be 'local.' They assert that a measuring device at station A cannot reasonably have an effect at station B, and that all the information brought by the signal from the source is therefore carried by the variable λ.

These interpretations and criticisms are inaccurate, however. To begin, the integral in Eq. (1) is an approximation of convenience for a sum of discrete events, and the factors A and B stand for sequences of such events (measurements). The arguments of the factors are just labels indicating what the measuring device settings are whenever a positive measurement is made. That is, the conditional probability contained in the expectation function, for example $A(a|b,\lambda)$, indicates only that a positive measurement was made at station A when its polarizer was set to a, given that a positive measurement was already seen at station B when its polarizer had setting b. Such terms are identified in the data stream *after-the-fact*; the presence of the setting b in the symbol for station A implies no more than that there is a correlation from a common cause which is revealed by the combination of measurement-device settings a and b. Nothing in this probabilistic formalism implies that the cause affecting the coincidences was propagated at superluminal velocities; indeed, this analysis is routinely use for obviously causal events in probability theory.

Further, the symbol λ in these expressions is essentially gratuitous. It stands for unknown information, and as such can be explicitely written always whenever statistical analysis is being done, because statistical analysis is used *only* when there is such unknown knowledge. In other cases, deterministic analysis and mathematics are the appropriate tool.

Insofar as this criticism is based ultimately on mathematics, it has been rediscovered repeatedly with different styles of reasoning and presentation. Perhaps the first to do so was Edwin Jaynes in 1988.(2) His guiding interest was a general formulation of what is virtually a philosophical position based on probabilities conditioned on estimates, as first suggested by Bayes. The essential point here is only that he recognized that Bell's logic failed to correctly use conditional probabilities. After Jaynes, the same error was rediscovered directly by at least Perdijon(3), Unnikrishnan(4), Khrennikov(5) and this writer(6; 7) as well as by dozens of others indirectly.

III. THE RE-ANALYSIS OF EXPERIMENTS

It is a simple tautology, that if the logical assumptions under which EPR experiments were conceived is in error, then whatever results they yield must be understandable in terms of conventional mathematics. For this matter, the central issue is just the coefficient of higher order correlation as introduced by Mandel and Glauber (in the West in any case[1]). The most general formula, which is in fact just a generalization of Malus' Law for polarizers, takes the form:

$$g^{(2n)}(\tau_1,\tau_2,\ldots,\tau_n) = \frac{< \prod_{j=n}^{j=1} E_j^*(r_j,t_j) E_j^*(r_j,t_j,\tau_j) \prod_{j=1}^{j=n} E(r_j,t_j,\tau_j) E(r_j,t_j) >}{\prod_{j=1}^{j=n} < |E_j^*(r_j,t_j) E_j(r_j,t_j)|^2 >}, \tag{4}$$

where the τ_j are the possible "offsets."

This writer has, using this formula, re-analyzed all the generic types of EPR and GHZ experiments nowadays cred-

[1] As the natural generalization of a formula known for over 200 years, very probably many have suggested and used it for various applications.

ited with demonstrating the validity of Bell's analysis. If Bell's analysis were correct, the classical form of this equation (which differs from the quantum version in that, *inter alia*, the factors E are *not* operators) should not give accurate results. That is, data taken in experiments should not conform to the classical variant of this equation. However, it precisely describes the results of all these experiments. These results have been reported in detail elsewhere and shall not be repeated here.(8; 9)

In the case of EPR-B, i.e., two-fold, experiments the data exhibits a simple sinusoidal variation, which, in spite of errors, could arise accidentally; that is, successful analysis with Eq. (4) may not preclude all doubt. This situation is completely evaded, on the other hand, with analysis of a four-fold experiments intended to exhibit teleportation. The variation of the coincident count as a function of the rotation angles of the polarizers in the four output channels, is not intuitive and sufficiently complicated, that it is very unlikely that the experimentally observed behavior would be accidentally calculated with an inappropriate formula.

In addition, all prototypical EPR-B experiment has been simulated digitally data-point by data-point, showing in complete detail how EPR correlations arise without involving nonlocality.(8) The only inputs playing a role at each detector are classical electromagnetic fields propagated to the detectors from the source along past light-cones, and noise at the detector. The algorithms for this simulation have been published openly for the convenience of critics.

In short, data taken in all the generic types of EPR and GHZ experiments can be explained using Eq. (4), a fully classical relationship. Were Bell's analysis correct, such should be impossible.

IV. AN OVERSIGHT

Students of Quantum Mechanics, lacking an intuitive interpretation, have taken a very formalistic approach to its analysis. This has fostered some prescriptions (or folk legends) that are not strictly correct. One such, is the impression that non commutivity is a characteristic of quantum structure. The fact is, however, that only *Hamiltonian canonically conjugate variables* do not commute by cause of quantum structure. Other source or causes of non commutativity have nothing to do with this feature of quantum theory and cannot be exploited for the investigation of fundamentally quantum properties and capabilities.(10)

This fact has immediate consequence for contemporary researches into the possibilities of exploiting quantum structure for computing, cryptology and the like. Most of the experiments intended to explore the possibilities for these applications attempt to exploit "entangled" polarization states of the "photon." However, what has just been argued above is, that "entanglement" of polarization is nothing other than ordinary correlation. But the misconstual goes still deeper. The geometric structure of polarization, is encoded in the group structure $SU(2)$. This group, which because it is non commuting, is thought by many to be fundamentally quantum in nature. This is wrong. The group $SU(2)$ is isomorphic to $SO(3)$, and this latter group encodes the behavior of rotations on the sphere, i.e., geometry, and not that of *Hamiltonian canonically conjugate variables* as imposed by quantum structure. Further, in view of the isomorphism, the underlying cause of non commutativity of one of these groups also must be the cause for the other group; in short, the non commutativity of any structure encoded by the group $SU(2)$ cannot be due to quantum mechanics. This may have practical consequences.

V. 'QUANTUM' COMPUTING

Nowadays, great hope is placed on the potential computing power of quantum algorithms. The essential advantage is to be gained by exploiting the fact that wave functions can be superpositions of many components, each one of which represent a separate computation, so that operating on the wave function, simultaneously operates on all the options represented by the superposition. It is envisioned that the quantum devices required to run these algorithms must be quantum systems, which inevitably means at the atomic scale, i.e., very small. Some experiments seem to indicate that the proposed quantum algorithms are well formulated, i.e., 'they work.'

But, as has been argued herein, the actual structure involved is not quantum at all, which might imply that the algorithms could run on macroscopic devices. Since macroscopic devices are very much easier to manufacture, at least with such devices the advantages of the high degree of parallelism resulting from superposition might be realized more easily. On the other hand, he implications of these considerations for 'quantum cryptology' are unclear to this writer.

VI. CONCLUSIONS

The study surveyed herein leads to the conclusion that there is no valid support for the contention that Quantum Mechanics somehow encompasses nonlocality, or whatever form or superluminal interaction. This would remove one of the central conflicts in modern physics between Quantum Mechanics and Relativity. In addition, it was argued that the structure of what nowadays is considered 'entangled' polarization states of photons, in fact is *not* based on quantum phenomena. This may have the practical consequence, that, if so called 'quantum computing algorithms' are in fact effective, as have been claimed by various experimenters, then they should also run on macroscopic, easily manufactured, devices.

Note: Preprints of Refs. ((6–10) can be downloaded at: `http://www.nonloco-physics.000freehosting.com`.

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[2] Preprints of Refs 6-9, 11 are down-loadable at: www.nonloco-physics.000freehosting.com