Bell's theorem refuted and 't Hooft's superdeterminism rejected as we factor quantum entanglements in full accord with commonsense local realism

Gordon Watson *

Abstract: Commonsense local realism (CLR) is the fusion of local-causality (no causal influence propagates superluminally) and physical-realism (some physical properties change interactively). Advancing our case for a local realistic quantum mechanics based wholly on CLR, we use undergraduate maths and a single unifying thought-experiment to jointly factor the quantum entanglements in EPRB and Aspect (2002). Such CLR factors (one factor relating solely to beables in Alice's domain, the other factor relating solely to beables in Bob's domain), refute Bell's theorem and eliminate the need for 't Hooft's superdeterminism.

Key words: Bell's integral, CLR, quantum-entangled factors, superdeterminism

On one supposition we absolutely hold fast; that of local/Einstein causality: "The real *factual* situation of the system S_2 is independent of what is done with the system S_1, which is spatially separated from the former," after Einstein (1949:85).

"It is a matter of indifference ... whether λ denotes a single variable or a set, or even a set of functions, and whether the variables are discrete or continuous. However, [Bell writes] as if λ were a single continuous parameter," Bell (1964:195). λ may denote "any number of hypothetical additional complementary variables needed to complete quantum mechanics in the way envisaged by EPR," Bell (2004:242).

1 Introduction

#**1.** Bound by commonsense local realism (CLR), the fusion of local-causality (no causal influence propagates superluminally) and physical-realism (some physical properties change interactively), we refute Bell's theorem and eliminate the need for 't Hooft's superdeterminism. Our approach thus differs diametrically from 't Hooft's, who "did not refute Bell's theorem but by-passed it by accepting superdeterminism," after G 't Hooft (2014, pers. comm., 1 July).

#**2.** In the context of Bell (1964) (available online, with other essays; see References), let Alice and Bob be two independent experimenters, adequately separated. And let us assume that, in the absence of communication between them, Bob's free-will cannot possibly be correlated with Alice's free-will, nor with whatever the source of the particles does. And vice-versa.

#**3**. 't Hooft (2014:139, etc.) claims that "this assumption, natural as it seems, must be false.

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Only 'superdeterminism' can explain the correlations you need to reproduce the quantum result [associated with Bell (1964)]. I accept superdeterminism, and the apparent 'conspiracy' that ensues, by arguing that the conspiracy is not at all as strange as it seems. Neither Alice nor Bob can change the settings they decided about earlier, without modifying the behaviour of the source of the particles. That's because they can't change the wave function of the universe from an ontic state into a superposition of ontic states," after G 't Hooft (2014, pers. comm., 27 July). "My deterministic particles know long in advance in what direction an experimenter will hold his polarisation filter," after G 't Hooft (2014, pers. comm., 1 July).

2 Analysis

#**4.** With CLR directly opposed to 't Hooft's views, and seeking to eliminate the need for superdeterminism in physics, we proceed as follows: Re Bell (1964), let the unnumbered equations between Bell's (14)-(15) be (14a)-(14c). Let unit-vectors $\mathbf{a}, \mathbf{b}, \mathbf{c}$ replace his $\vec{a}, \vec{b}, \vec{c}$. Let Z be shorthand for EPRB, the experiment that Bell (1964) considers. Let expectation $\langle A(\mathbf{a})B(\mathbf{b}) \mid Z\rangle$ replace Bell's equivalent term $P(\vec{a}, \vec{b})$; etc. Let $P(. \mid Z)$ denote a probability conditioned on Z; etc.

#**5.** Further, when clarity requires, let primes ($'$) identify elements in Bob's domain. Then, under the conservation of total angular momentum in EPRB and (for later) in Aspect (2002), let $\lambda_i + \lambda_i' = 0$; ie, $\lambda_i' = -\lambda_i$ in the ith test. Thus, in that we typically work with such twinned particles (for such particle-pairs are the primary entities here), we use the shorthand $(\lambda, \lambda') \equiv (\lambda, -\lambda)$ for all λ-pairs in our analysis here; fully expecting no two pairs to be the same.

"In a complete physical theory of the type envisioned by Einstein, the hidden variables would have dynamical significance and laws of motion; our λ can be thought of as initial values of these variables at some suitable instant," Bell (1964:196).

#**6.** Finally, taking maths to be the best logic and wanting our maths to do the talking, let's combine Bell's (1)-(3) and (12)-(13) in our terms:

$$A(\mathbf{a}, \lambda) = \pm 1 \equiv A^{\pm};\ B(\mathbf{b}, \lambda') = B(-\lambda, \mathbf{b}) = \pm 1 \equiv B^{\pm};\ \int d\lambda \rho(\lambda) = 1; \tag{1}$$

$$\langle A(\mathbf{a})B(\mathbf{b}) \,|\, Z\rangle = \int d\lambda \rho(\lambda) A(\mathbf{a}, \lambda) B(-\lambda, \mathbf{b}) \neq -\mathbf{a}\cdot\mathbf{b}. \tag{2}$$

#**7.** (1) captures the vital CLR assumption, an assumption in full accord with Bell (1964:196) and Einstein (1949:85): the result B does not depend on the setting $\mathbf{a}$; nor A on $\mathbf{b}$.

#**8.** (2) is, in our terms, "Bell's impossibility theorem" or "Bell's second theorem" – CHSH (1969) first coining the term "Bell's theorem" in the context of Bell 1964:(15). Now Watson (2014d) refutes Bell's 1964:(14a): the false equality which underpins Bell's 1964:(15) and hence his inequality in (2) above. This result is consistent with Watson (2014a:7-8), which provides a functional refutation of (1)-(2) in the context of Mermin's (1990; 1990a) 3-particle GHZ-variant.

#**9.** However, to specifically address 't Hooft's reference to ontic states, we now take a different approach. Under CLR, we now show that the probability of any EPRB-style result is determined by local factors (CLR base-factors) alone; one factor based solely on beables in Alice's domain, the other factor based solely on beables in Bob's domain.

#**10.** To that end, let s denote relevant spins: ie, $s = 1/2$ for the spin-$1/2$ particles in EPRB, experiment Z; $s = 1$ for the photons in Aspect (2002), experiment X; $s = \frac{1}{2}$ or 1 for the particles in our unifying thought-experiment Q. That is, as will be seen: demonstrating the unifying influence of CLR, experiment Q reduces EPRB and Aspect (2002) to a single experiment. Thus, under Q, and using CLR base-factors, a generalized base-factor derivation of the related quantum mechanical expectations for Q, Z, X follows.

#11. Let $|A^+\rangle$ and $|A^-\rangle$ denote the ontic states for which Alice's outcomes are $A^+ (= +1)$ and $A^- (= -1)$ respectively, per (1); etc. Let a trigonometric argument $(\mathbf{u},\mathbf{v})$ denote the angle between vectors $\mathbf{u}$ and $\mathbf{v}$. Then, requiring only that CLR base-factors ψ be well-behaved (by which we mean, normalized and not misleading) when entangled under integrals, let:

$$\psi(\mathbf{a},\lambda)_Q = (\sqrt{2}\cos^2(s(\lambda,\mathbf{a})) \pm \tfrac{1}{2})\left|A^+\right\rangle - (\sqrt{2}\sin^2(s(\lambda,\mathbf{a})) \pm \tfrac{1}{2})\left|A^-\right\rangle; \tag{3}$$

$$\psi(\mathbf{b},-\lambda)_Q = (\sqrt{2}\cos^2(s(\lambda,\mathbf{a})) \mp \tfrac{1}{2})\left|B^+\right\rangle - (\sqrt{2}\sin^2(s(\lambda,\mathbf{a})) \mp \tfrac{1}{2})\left|B^-\right\rangle. \tag{4}$$

$$\therefore \Psi(A(\mathbf{a})B(\mathbf{b})\,|\,Q) \equiv \int_Q d\lambda\rho(\lambda)\psi(\mathbf{a},\lambda)_Q\psi(\mathbf{b},-\lambda)_Q \tag{5}$$

$$\begin{aligned} = \int_0^{4\pi} \frac{d\lambda}{4\pi}[&(\sqrt{2}\cos^2(s(\lambda,\mathbf{a})) \pm \tfrac{1}{2})(\sqrt{2}\cos^2(s(\lambda,\mathbf{b})) \mp \tfrac{1}{2})\left|A^+B^+\right\rangle \\ &-(\sqrt{2}\cos^2(s(\lambda,\mathbf{a})) \pm \tfrac{1}{2})(\sqrt{2}\sin^2(s(\lambda,\mathbf{b})) \mp \tfrac{1}{2})\left|A^+B^-\right\rangle \\ &-(\sqrt{2}\sin^2(s(\lambda,\mathbf{a})) \pm \tfrac{1}{2})(\sqrt{2}\cos^2(s(\lambda,\mathbf{b})) \mp \tfrac{1}{2})\left|A^-B^+\right\rangle \\ &+(\sqrt{2}\sin^2(s(\lambda,\mathbf{a})) \pm \tfrac{1}{2})(\sqrt{2}\sin^2(s(\lambda,\mathbf{a})) \mp \tfrac{1}{2})\left|A^-B^-\right\rangle] \end{aligned} \tag{6}$$

$$\begin{aligned} &= \tfrac{1}{2}(\cos^2(s(\pi+(\mathbf{a},\mathbf{b}))))\left|A^+B^+\right\rangle - \tfrac{1}{2}(\sin^2(s(\pi+(\mathbf{a},\mathbf{b}))))\left|A^+B^-\right\rangle \\ &- \tfrac{1}{2}(\sin^2(s(\pi+(\mathbf{a},\mathbf{b}))))\left|A^-B^+\right\rangle + \tfrac{1}{2}(\cos^2(s(\pi+(\mathbf{a},\mathbf{b}))))\left|A^-B^-\right\rangle. \end{aligned} \tag{7}$$

$$\therefore \langle A(\mathbf{a})B(\mathbf{b})\,|\,Q\rangle = \cos^2(s(\pi+(\mathbf{a},\mathbf{b}))) - \sin^2(s(\pi+(\mathbf{a},\mathbf{b}))) = \cos(2s(\pi+(\mathbf{a},\mathbf{b}))). \tag{8}$$

$$\therefore \langle A(\mathbf{a})B(\mathbf{b})\,|\,Z\rangle = \left\langle A(\mathbf{a})B(\mathbf{b})\,|\,Q, s=\tfrac{1}{2}\right\rangle = \langle A(\mathbf{a})B(\mathbf{b})\,|\,EPRB\rangle = -\cos(\mathbf{a},\mathbf{b}) = -\mathbf{a}\cdot\mathbf{b}; \tag{9}$$

$$\langle A(\mathbf{a})B(\mathbf{b})\,|\,X\rangle = \langle A(\mathbf{a})B(\mathbf{b})\,|\,Q, s=1\rangle = \langle A(\mathbf{a})B(\mathbf{b})\,|\,\text{Aspect (2002)}\rangle = \cos 2(\mathbf{a},\mathbf{b}). \blacksquare \tag{10}$$

#12. QED. In (9), Bell's second theorem, (2) above, is refuted via the correct CLR-based derivation of the EPRB expectation. Bell's first theorem, his 1964:(15), is consequently and independently refuted by substitutions based on (9). In (10), Aspect's (2002) expectation is correctly delivered. And in (7), 't Hooft's (2014) need for a superposition of ontic states is met.

#13. However, a core issue remains: What functions did Bell have in mind for (1) above and for "Bell's integral" in (2) above? We know one thing: whatever his ideas, they must satisfy the following analysis (and his published works do not). That is, starting afresh with (5), and using (7) on a particle-by-particle basis:

$$\langle A(\mathbf{a})B(\mathbf{b})\,|\,Q\rangle = \int_Q d\lambda\rho(\lambda)A(\mathbf{a},\lambda)_QB(\mathbf{b},-\lambda)_Q \tag{11}$$

$$= \int_Q d\lambda\rho(\lambda)[P(A^+_\lambda B^+_{-\lambda}\,|\,Q) - P(A^+_\lambda B^-_{-\lambda}\,|\,Q) - P(A^-_\lambda B^+_{-\lambda}\,|\,Q) + P(A^-_\lambda B^-_{-\lambda}\,|\,Q)] \tag{12}$$

$$\begin{aligned} = \int_Q d\lambda\rho(\lambda)[&P(A^+_\lambda\,|\,Q)P(B^+_{-\lambda}\,|\,QA^+_\lambda) - P(A^+_\lambda\,|\,Q)P(B^-_{-\lambda}\,|\,QA^+_\lambda) \\ &- P(A^-_\lambda\,|\,Q)P(B^+_{-\lambda}\,|\,QA^-_\lambda) + P(A^-_\lambda\,|\,Q)P(B^-_{-\lambda}\,|\,QA^-_\lambda)] \end{aligned} \tag{13}$$

$$= \tfrac{1}{2}\int_Q d\lambda\rho(\lambda)[P(B^+_{-\lambda}\,|\,QA^+_\lambda) - P(B^-_{-\lambda}\,|\,QA^-_\lambda) - P(B^+_{-\lambda}\,|\,QA^-_\lambda) + P(B^-_{-\lambda}\,|\,QA^-_\lambda)] \tag{14}$$

$$= \tfrac{1}{2}[\cos^2(s(\pi + (\mathbf{a}, \mathbf{b}))) - \sin^2(s(\pi + (\mathbf{a}, \mathbf{b}))) - \sin^2(s(\pi + (\mathbf{a}, \mathbf{b}))) + \cos^2(s(\pi + (\mathbf{a}, \mathbf{b})))]. \quad (15)$$

#14. In moving from (13)-(14), the integral is surplus in this particle-by-particle analysis since the probability of each result is a constant of the experiment. We conclude, in full accord with CLR: Given Q, with random λ and $s = \frac{1}{2}$ or $s = 1$, the outcomes for any particle-pair are statistically-dependent:

$$P(B^{+}_{-\lambda}\,|QA^{+}_{\lambda}) = P(B^{-}_{-\lambda}\,|QA^{-}_{\lambda}) = \cos^2(s(\pi + (\mathbf{a}, \mathbf{b}))); \quad (16)$$

$$P(B^{+}_{-\lambda}\,|QA^{-}_{\lambda}) = P(B^{-}_{-\lambda}\,|QA^{+}_{\lambda}) = \sin^2(s(\pi + (\mathbf{a}, \mathbf{b}))); \quad (17)$$

$$P(A^{+}_{\lambda}\,|Q) = P(A^{-}_{\lambda}\,|Q) = \tfrac{1}{2}. \quad (18)$$

#**15**. (18), derived independently from CLR factors – and used in the move (12)-(13) above – confirms that each λ is a random variable in 3-space. Then, in that (11) applies to each individual interaction, our results apply to λ_i and $-\lambda_i$ in the ith pair; to λ_j and $-\lambda_j$ in the jth pair; etc. That is: the constants of the experiment are clear in the denouement (11)-(18).

3 Conclusions

#16. As expected, our results continue to refute Bell's theorem to our total satisfaction: for all loopholes are closed under CLR. The physical significance of CLR's factor-analysis is evident in (8)-(10); for there we find the correct expectations for experiment Q, for EPRB (RHS of (2) above), and for Aspect 2002:(6). Moreover, any probability $P(.\mid Q)$ can be derived from such factors.

#17. Based on (2) above, Bell's 'impossibility theorem' is doubly refuted, via (9)-(10), as CLR continues to deliver the correct quantum mechanical expectations for important experiments.

#18. That is: Based on the way Bell presents his case, the implicit assumption in Bell's 1964:(2) integral – see (2) above – is statistical independence, particle-pair by particle-pair. But the facts are otherwise: particle-pair by particle-pair, the results are causally independent per (1) and statistically dependent/correlated per (7). As shown, in full accord with our CLR mantra: Correlated tests (correlated by $(\mathbf{a}, \mathbf{b})$) on correlated things (particle-pairs with $\lambda = -\lambda'$ in each pair) produce correlated results (A, B) and the appropriate expectation $(\cos(2s(\pi + (\mathbf{a}, \mathbf{b}))))$ without mystery.

#19. We conclude that Bell's theorem is irrelevant to any serious physical theory. In particular, it should no longer be a constraint on 't Hooft's (2014) program, especially not at 't Hooft 2014:(8.22)-(8.23). Finally, reviewing paragraph #2 in the light of all our results, we conclude that Alice and Bob have sufficient free-will to complete any experiment to our CLR satisfaction. For, in refuting Bell's theorem, we eliminate the need for 't Hooft's superdeterminism in physics.

#20. So the story that began with Mermin (1988) continues. And thanks to viXra.org, there's http://vixra.org/abs/1405.0020: a rough draft that also meets Bell's (1990:10) expectation that relativity and quantum mechanics would be reconciled; ie, it too delivers Bell's hope (2004: 167) for a simple constructive locally-causal (CLR) model of reality like that above.

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