# Bell's theorem is silly, false, misleading

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1 October 2015: A reply to the challenge, "What's your problem with Bell's theorem?"

## 1 Bell's theorem

#1.1. In my terms — given Bell (1964) and EPRB defined by (1)-(2) — (3) is Bell's theorem:

$$. A^{\pm} \equiv \pm 1 = A_i \Leftarrow D(\mathbf{a}) \leftarrow p(\lambda_i) \leftarrow S_{EPRB} \rightarrow p(\lambda_i') \rightarrow D(\mathbf{b}) \Rightarrow B_i = \pm 1 \equiv B^{\pm}. \tag{1}$$

$$\textbf{Given } A(\mathbf{a}, \lambda_i) = \pm 1 \equiv A^{\pm},\ B(\mathbf{b}, \lambda_i') = \pm 1 \equiv B^{\pm},\ \lambda_i + \lambda_i' = 0,\ \int \rho(\lambda) d\lambda = 1, \tag{2}$$

$$\textbf{then } \left\langle AB \,|\, Q_{\frac{1}{2}} \right\rangle \equiv \langle AB \,|\, EPRB \rangle = -\frac{1}{n} \sum_{i=1}^{n} A(\mathbf{a}, \lambda_i) A(\mathbf{b}, \lambda_i) \neq -\mathbf{a}.\mathbf{b}. \tag{3}$$

#1.2. $S_{EPRB}$ delivers EPRB-correlated particles. Detectors $D$ are polarizer-analyzers. The principal-axis of Alice's dichotomic linear-polarizer is oriented **a** in 3-space, Bob's **b**. The respective analyzer-outputs are $A^{\pm}$ and $B^{\pm}$. $Q_*$ denotes experiments here; eg, EPRB [$Q_{\frac{1}{2}}$], Aspect (2002) [$Q_1$]. Based on Bell (1964): it's a matter of indifference whether $\lambda$ denotes a single variable or a set, or whether the variables are discrete or continuous. (I associate spin $s$ with $\lambda$. In (2), pristine $\lambda_i$ and $\lambda_i'$ are correlated by the conservation of angular momentum.) Given Einstein-locality, local particle/detector interactions yield local results. $A_i$ is thus determined by **a** and $\lambda_i$ alone, $B_i$ by **b** and $\lambda_i'$ alone.

#1.3. $\langle AB \mid . \rangle$ replaces Bell's $P(\mathbf{a}, \mathbf{b})$ notation. When required, primes ($'$) identify elements in Bob's locale. Index $i$ identifies each particle-pair from $\{p(\lambda_i),\ p(\lambda_i') \mid Q_*;\ i = 1, 2, ..., n\}$, a set that is built as pairs from the designated source $Q_*$ are detected. $n$ provides an adequate accuracy. Based on local beables, my $\lambda$ is a random unit-vector in 3-space with a uniform distribution. It is thus probability zero that any two particle-pairs are the same. Hence probability one that $\lambda_i \neq \lambda_{n+i}$ in general.

#1.4. Of course, were we conducting classical tests on classical objects, then $\lambda_i = \lambda_{n+i}$ would be possible. But neither my local-realism nor the EPRB experiment is constrained by such limiting classicality. Nor am I bound here by Bell's interpretation of EPR (1935). (I share Einstein's dissatisfaction with EPR and I reject naive-realism as a general principle.) However, to be clear regarding Bell's theorem: I will refute it and related erroneous statements. Including Bell's (1990:5), "I cannot say that action at a distance is required in physics. But I can say that you cannot get away with no action at a distance." Goldstein *et al.* (2011), 'experiments establish that our world is non-local.' Maudlin (2014), "Non-locality is here to stay." So my focus here is on experiments and the principle of locality.

> "The paradox of Einstein, Podolsky and Rosen [EPR (1935)] was advanced as an argument that quantum mechanics could not be a complete theory but should be supplemented by additional variables [λ]. These additional variables were to restore to the theory causality and locality [Einstein (1949:85); see #3.1 below]. In this note that idea will be formulated mathematically [in the context of EPRB] and shown to be incompatible with the statistical predictions of quantum mechanics. It is the requirement of [Einstein] locality [...] that creates the essential difficulty," Bell (1964:195).

#1.5. The excision [...] reads: "or more precisely that the result of a measurement on one system be unaffected by operations on a distant system with which it has interacted in the past." But I take Einstein-locality, as defined in (1)-(2), to be: (i) broader than Bell's narrow 'precision' here. (ii) mathematically clean; refuting (as will be seen) Bell's later *locally causal theorizing* (2004:54, Eq. 2).

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## 2 Bell's theorem is silly

#2.1. So. To prove his inequality in (3) – "The main result will now be proved," Bell (1964:197). – Bell goes beyond (1)-(3) and invokes **c** (a third unit-vector) in three unnumbered equations following his 1964:(14). Number them (14a)-(14c); then Bell has (14b) = (14a). I now show the *silly limiting restriction* required for this Bellian equality to go through.

$$\text{Bell's (14a)} = \langle AB\rangle - \langle AC\rangle = -\frac{1}{n}\sum_{i=1}^{n}[A(\mathbf{a},\lambda_i)A(\mathbf{b},\lambda_i) - A(\mathbf{a},\lambda_{n+i})A(\mathbf{c},\lambda_{n+i})] \tag{4}$$

$$= \frac{1}{n}\sum_{i=1}^{n} A(\mathbf{a},\lambda_i)A(\mathbf{b},\lambda_i)[A(\mathbf{a},\lambda_i)A(\mathbf{b},\lambda_i)A(\mathbf{a},\lambda_{n+i})A(\mathbf{c},\lambda_{n+i}) - 1]. \tag{5}$$

#2.2. (5) is the discrete form of Bell's (14a). And I accept Bell's (14b) = (14c). However: I question Bell's (14b) = (14a) under EPRB. So I have (5) = (14a) $\stackrel{?}{=}$ (14b) = (14c). That is,

$$\text{from Bell's (14b)-(14c)-(15): } \langle BC\rangle \equiv -\frac{1}{n}\sum_{i=1}^{n} A(\mathbf{b},\lambda_i)A(\mathbf{c},\lambda_i) = -\frac{1}{n}\sum_{i=1}^{n} A(\mathbf{b},\lambda_{n+i})A(\mathbf{c},\lambda_{n+i}) \tag{6}$$

$$\stackrel{?}{=} -\frac{1}{n}\sum_{i=1}^{n} A(\mathbf{a},\lambda_i)A(\mathbf{b},\lambda_i)A(\mathbf{a},\lambda_{n+i})A(\mathbf{c},\lambda_{n+i}); \text{ from (5) = from Bell's (14a).} \tag{7}$$

#2.3. Alas, to remove the question-mark from (7) and justify his (14b) = (14a), Bell requires the probability zero $\lambda_i = \lambda_{n+i}$ : *probability zero* because, in the context of EPRB with probability one, $\lambda_i \neq \lambda_{n+i}$ in general (#1.2-1.3). So here are two genuine EPRB-based inequalities:

$$-\frac{1}{n}\sum_{i=1}^{n} A(\mathbf{a},\lambda_i)A(\mathbf{b},\lambda_i)A(\mathbf{a},\lambda_{n+i})A(\mathbf{c},\lambda_{n+i}) \neq -\frac{1}{n}\sum_{i=1}^{n} A(\mathbf{b},\lambda_i)A(\mathbf{c},\lambda_i) = \langle BC\rangle\,. \tag{8}$$

$$\text{Bell 1964: (14b)} \neq \text{Bell 1964: (14a).} \tag{9}$$

#2.4. (9) is the source of the false inequality in (3): Bell's (14b) = (14a) is false under EPRB. (8) exposes the naive-realism behind Bell's theorem and much Bellian thinking. For example:

> "To explain this dénouement [eg, in Bell 1964:(14)-(15); the subject of (4)-(9) above] without mathematics I cannot do better than follow d'Espagnat (1979; 1979a)," Bell (2004:147).
>
> Here's d'Espagnat (1979:166), recast for EPRB: 'One can infer that in *every particle-pair*, one particle has the property $A^+$ and the other has the property $A^-$, one has property $B^+$ and one $B^-$, and one has property $C^+$ and one $C^-$. Such conclusions require a subtle ... extension of the meaning assigned to our notation $A^+$. Whereas previously $A^+$ was merely one possible outcome of a measurement made on a particle, it is converted by this argument into an attribute of the particle itself. To be explicit, if some unmeasured particle has the property that a measurement along the axis $A$ would give the definite result $A^+$, then that particle is said to have the property $A+$. In other words, the physicist has been led to the conclusion that both particles in each pair have definite spin components at all times. ... This view is contrary to the conventional interpretation of quantum mechanics.'

#2.5. Now, as stated above at #1.4: were we conducting classical tests on classical objects, then $\lambda_i = \lambda_{n+i}$ would be possible. And Bell's theorem would then hold routinely (not profoundly). But here's Bell in 1987, against his view in #2.4:

> "... the result of a 'measurement' does not in general reveal some preexisting property of the 'system', but is a product of both 'system' and 'apparatus'. It seems to me that full appreciation of this would have aborted most of the 'impossibility proofs' [like Bell's theorem?], and most of quantum logic'," Bell (2004: xi-xii).

#2.6. Agreeing, I conclude: Based on Bell's naive-realism in the context of EPRB, Bell's theorem is silly – a conclusion in full accord with Bell's later thinking:

"Now, it's my feeling that all this action at a distance and no action at a distance business will go the same way [eg, as the ether]. But someone will come up with the answer, with a reasonable way of looking at these things. If we are lucky it will be to some big new development like the theory of relativity. *Maybe someone will just point out that we were being rather silly*, and it won't lead to a big new development. But anyway, I believe the questions will be resolved," Bell (1990:9) with added emphasis.

## 3 Bell's theorem is false

#3.1. I now prove Bell's theorem false and refute a common Bellian implication:

> "Einstein argued that the EPR correlations could be made intelligible only by completing the quantum mechanical account in a classical way. But detailed analysis shows that any classical account of these correlations has to contain just such a 'spooky action at a distance' [Einstein in Born (1971:158)] as Einstein could not believe in. [For Einstein believed]:
>
> > 'But on one supposition we should, in my opinion, absolutely hold fast: 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,' Einstein (1949:85).
>
> If nature follows quantum mechanics in these correlations, then Einstein's conception of the world is untenable," Bell (2004:86).

#3.2. Now Bell's premise is true: nature does indeed follow quantum mechanics in EPRB correlations. But Bell's conclusion is false: as will be seen by my completion of the quantum mechanical account in a classical local-realistic way. That is: Taking realism to be the view that external reality exists and has definite properties, my analysis will be bound by local-causality (no causal influence propagates superluminally) and physical-realism (some physical properties change interactively).

#3.3. In the face of unknowns like $\lambda_i$, I begin with classical probability theory (the science of logical inference) and a thought-experiment $Q_s$. Based on particles with spin $s = \frac{1}{2}$ or 1, $Q_s$ is designed to take me from old certainties to new. For me, old certainties are provided and confirmed by experiments – eg, Aspect's (2002) experiment (denoted $Q_1$, the subscript indicating the related spin $s$) – as I seek new certainties re EPRB (denoted $Q_{\frac{1}{2}}$). As in Aspect (2002) and EPRB, the expectation for $Q_s$ is:

$$\langle AB \mid Q_s\rangle \equiv P(A^+B^+ \mid Q_s) - P(A^+B^- \mid Q_s) - P(A^-B^+ \mid Q_s) + P(A^-B^- \mid Q_s) \tag{10}$$

$$= 4P(A^+B^+|Q_s) - 1 \text{ (11.1)} = 4P(A^+|Q_s)P(B^+|Q_sA^+) - 1 \text{ (11.2)} = 2P(B^+|Q_sA^+) - 1 \text{ (11.3)}. \tag{11}$$

#3.4. To be clear on a crucial point in the context of Bell's theorem: consistent with my local-causality (no causal influence propagates superluminally), no causal influences are invoked, required or implied in (10)-(11). Then, identifying the sub-equalities in (11) as (11.1)-(11.3):

#3.5. Given (10): (11.1) follows via the symmetry of the $Q_s$-state; ie,

$$P(A^+B^+ \mid Q_s) = P(A^-B^- \mid Q_s);\ P(A^+B^- \mid Q_s) = P(A^-B^+ \mid Q_s). \tag{12}$$

#3.6. Given (11.1): (11.2) can never be false in classical probability theory.

#3.7. Given (11.2): (11.3) follows via $P(A^+|Q_s) = P(B^+|Q_s) = \frac{1}{2}$ : since $\lambda$ is a random variable.

#3.8. Given (11.3) and quantum theory, $Q_s$ delivers these predictions:

$$\langle AB|Q_s\rangle = 2P(B^+|Q_sA^+) - 1 = \cos 2s(\pi \pm (\mathbf{a}, \mathbf{b})), \tag{13}$$

$$\therefore P(B^+|Q_sA^+) = \tfrac{1}{2}(1 + \cos 2s(\pi \pm (\mathbf{a}, \mathbf{b}))) : \tag{14}$$

$$P(B^+|Q_1A^+) = \cos^2(\mathbf{a}, \mathbf{b}) \rightarrow \textbf{in agreement with Aspect's (2002) experiment}. \tag{15}$$

$$P(B^+|Q_{\frac{1}{2}}A^+) = \sin^2 \tfrac{1}{2}(\mathbf{a}, \mathbf{b}) \rightarrow \textbf{a prediction for EPRB, the experiment in Bell (1964)}. \tag{16}$$

#3.9. To be clear: with certainty, (16) will be adequately confirmed under EPRB, just as (15) is adequately confirmed under Aspect (2002). So, with certainty, (16) leads to (3) being corrected to:

$$\left\langle AB|Q_{\frac{1}{2}}\right\rangle \equiv \langle AB|EPRB\rangle = -\mathbf{a}.\mathbf{b}; \tag{17}$$

ie, an equality replaces Bell's inequality in (3), with (17) confirmed by substituting $s = \frac{1}{2}$ in (13).

#3.10. Supporting Einstein's argument for completing the quantum mechanical account of EPRB correlations in a classical way, I conclude: Bell's theorem is false. A result that delivers Bell's (2004:167) hope for a simple constructive model of reality based on local causality and Bell's (1990:10) expectation that relativity and quantum mechanics would one day be reconciled (see #5.2).

## 4 Bell's theorem is misleading

#4.1. To date, much research on Bell's theorem follows Bell's naive-realism (#2.4) into error. Examples include: Goldstein *et al.* (2011), "In light of Bell's theorem, [many] experiments ... establish that our world is non-local. This conclusion is very surprising, since non-locality is normally taken to be prohibited by the theory of relativity." Maudlin (2014), "Non-locality is here to stay ... the world we live in is non-local." But surely few err more than Bell when he is misled to another 'theorem'?

#4.2. So I now address Bell's *local inequality theorem*: foreshadowed by Bell in 1987 (see Bell 2004: xii) and delivered in 1990 (Bell 2004:232-248). Tellingly, as will be shown, the theorem relies on falsely factoring a probability distribution to deliver the naively-false CHSH (1969) inequality (see #4.12).

#4.3. According to classical probability theory (#3.6): since (11.1) is true, (11.2) never can be false. Yet Bell repeatedly and mistakenly rejects such expressions, even in his final essay: see Bell (2004:243) and his move there from his (9) to his (10); equating *causal independence* to *statistical independence* as a consequence of *local causality*. A view most gardeners with adjoining crops reject. For, in keeping with Einstein-locality: *correlated causes*, not *direct causation*, link *causally independent results* (no mutual influence) like those in (1)-(2) to local-realistic correlations like those in (13)-(16).

#4.4. Indeed: given (11.1), the *slightest correlation* calls forth that never-can-be-false (11.2). And Bell recognizes the centrality of *correlation* (which is by no means slight) in EPRB:

> Recasting Bell (2004:208) in line with (1)-(3): "There are no 'messages' in one system from the other. The inexplicable [sic] correlations of quantum mechanics do not give rise to signalling between noninteracting systems. Of course, however, there may be correlations (eg, those of EPRB) and if something about the second system is given (eg, that it is the other side of an EPRB setup) and something about the overall state (eg, that it is the EPRB singlet state) then inferences from events in one system [eg, $A^+$ from Alice's detector] to events in the other [eg, $B^+$ from Bob's detector] are possible."

#4.5. So. Putting it plainly: in EPRB, under classical probability theory, the correlation between $A^+$ and $B^+$ *demands* (11.3). And in this way the following issue is resolved.

> "One general issue raised by the debates over locality is to understand the connection between stochastic independence (probabilities multiply) [ie, $P(XY) = P(X)P(Y)$] and genuine physical independence (no mutual influence) [ie, there is no mutual influence between $A_i^+(\mathbf{a}, \lambda_i)$ and $B_i^+(\mathbf{b}, \lambda_i')$]. It is the latter that is at issue in 'locality,' but it is the former that goes proxy for it in the Bell-like calculations. We need to press harder and deeper in our analysis here," Arthur Fine, in Schlosshauer (2011:45).

#4.6. Our pressing, thus far, proves the following (contra Bell): when outcomes are correlated as in $Q_s$, stochastic independence is no proxy for local-causality. So we now press on to finality via $Q_c$, a classical thought-experiment in which *now-polarized* particles are pair-wise correlated by $\phi_i + \phi_i' = 0$. That is, following Bell's (2004:166) dictum – "Always test your general reasoning against simple models." – $Q_c$ is (with certainty) a classical locally-causal experiment with causally-independent outcomes. [NB: The $Q_s$-state, invariant under rotations in 3-space, breaches the CHSH inequality. The $Q_c$-state, with its reduced correlation (invariant under rotations about the line of flight only), does not.]

#4.7. To convert $Q_s$ to $Q_c$ we sandwich the $Q_s$ source between two yoked single-channel linear-polarizers. The polarizers are so coupled that, at all times: their principal-axes are parallel to each other while their common rotation is constrained to be orthogonal to the line of flight of each particle-pair. Thus aligned, the polarizers step randomly (in unison) about the line of flight to orientation $\phi_i$ for the $i$-th test. As before, from (10)-(11):

$$\langle AB \mid Q_c\rangle \equiv P(A^+B^+ \mid Q_c) - P(A^+B^- \mid Q_c) - P(A^-B^+ \mid Q_c) + P(A^-B^- \mid Q_c) \tag{18}$$

$$= 4P(A^+B^+|Q_c) - 1 \ (19.1) = 4P(A^+|Q_c)P(B^+|Q_cA^+) - 1 \ (19.2) = 2P(B^+|Q_cA^+) - 1 \ (19.3). \quad (19)$$

#4.8. Then, consistent with local causality and causal independence (ie, no mutual influence):

$$P(A^+|Q_c, s, \mathbf{a}, \phi) = \tfrac{1}{2\pi}\int d\phi \cos^2 s(\mathbf{a}, \phi) = P(B^+ \mid Q_c, s, \mathbf{b}, \phi') = \tfrac{1}{2\pi}\int d\phi \cos^2 s(\mathbf{b}, \phi') = \tfrac{1}{2}. \quad (20)$$

$$\therefore \tfrac{1}{4} = P(A^+ \mid Q_c)P(B^+ \mid Q_c) \neq P(A^+B^+ \mid Q_c) = \tfrac{1}{2\pi}\int d\phi \cos^2 s(\mathbf{a}, \phi) \cos^2 s(\mathbf{b}, \phi') \quad (21)$$

$$= \tfrac{1}{8}(2 + \cos 2s(\pi \pm (\mathbf{a}, \mathbf{b}))) = P(A^+ \mid Q_c)P(B^+ \mid Q_cA^+). \quad (22)$$

#4.9. Thus. Comparing LHS (21) with (22), we refute another Bellian fad. Recasting Bell (2014:243) in terms of #4.8 for easier understanding:

> "Factorization – like $P(A^+|Q_c)P(B^+|Q_c)$ in LHS (21) – is often taken as the starting point of the analysis. I [John Bell] prefer to see it not as the *formulation* of 'local causality', but as a **consequence** thereof," with my bolding.

#4.10. However. From (20), $A^+$ and $B^+$ are (clearly) locally-casual and causally-independent. So the expression $P(A^+B^+ \mid Q_c)$ in (21) is (clearly) an *unfactored locally-causal formulation*. Alas, for Bell's new theorem, failure follows: for the combination of factorization and stochastic independence that Bell seeks is *an impossibility*; and not in any way *a consequence* of $P(A^+B^+ \mid Q_c)$. That is:

#4.11. The expression $P(A^+ \mid Q_c)P(B^+ \mid Q_c)$ in LHS (21) is refuted by the factorization in (22): (22) flowing directly from that *unfactored locally-causal formulation* $P(A^+B^+ \mid Q_c)$ in (21). Thus, confirming Bell's (2004:239) "utmost suspicion" regarding his own work toward a locally causal theory:

Bell threw the baby out with the bathwater.

#4.12. Moreover, despite Bell's factorization being rejected as above, further confirmatory trouble follows. For, per Bell (2004: xii): via his *local inequality theorem*, the CHSH (1969) inequality is obtained. But experiments testing the CHSH inequality take a form like this:

$$\frac{1}{n}\sum_{i=1}^{n}[A_iB_i + B_{n+i}C_{n+i} + C_{2n+i}D_{2n+i} - A_{3n+i}D_{3n+i}]; \quad (23)$$

whereas the CHSH inequality itself requires

$$\frac{1}{n}\sum_{i=1}^{n}[A_i(B_i - D_{2n+i}) + C_{n+i}(B_i + D_{2n+i})] \quad (24)$$

via equalities with probability zero (after #1.3 and #2.3):

$$A_i = A_{3n+i},\ B_i = B_{n+i},\ C_{n+i} = C_{2n+i},\ D_{2n+i} = D_{3n+i}. \quad (25)$$

#4.13. I take the lesson to be this. Bell's misleading (3): (i) led CHSH to their naively-false inequality. (ii) encouraged Bell to seek an alternate route to the erroneous CHSH result via his erroneous *local inequality theorem*. (iii) stoked Bell's ambivalence re action at a distance; eg, from Bell (1990):

> "... I cannot say that action at a distance is required in physics. But I can say that you cannot get away with no action at a distance. You cannot separate off what happens in one place and what happens in another. Somehow they have to be described and explained jointly. Well, that's just the fact of the situation; the Einstein program fails, that's too bad for Einstein, but should we worry about that?" (pp.5-6). "And it might be that we have to learn to accept not so much action at a distance, but [the] inadequacy of no action at a distance," (p.6). "And that is the dilemma. We are led by analyzing this situation to admit that in somehow distant things are connected, or at least not disconnected," (p.7). "I don't know any conception of locality which works with quantum mechanics. So I think we're stuck with nonlocality," (p.12). "There is no energy transfer and there is no information transfer either. That's why I am always embarrassed by the word action, and so I step back from asserting that there is action at a distance, and I say only that you cannot get away with locality. You cannot explain things by events in their neighbourhood. But, I am careful not to assert that there is action at a distance," (p.13).

#4.14. Given extensive research on the subject – eg, Bell himself, CHSH (1969), Goldstein *et al.* (2011), Maudlin (2014): all bound by a naive-realism, yet none corrected in the face of many experimental refutations – I rest my case that Bell's theorem (3) is misleading.

## 5 Conclusion

#5.1. Given #2.6, #3.10, #4.14, I conclude as I began in 1989: Bell's theorem is silly, false, misleading. For this next is true:

> 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 (Einstein 1949): under $Q_*$, correlated tests $D(\mathbf{a})$ and $D(\mathbf{b})$ on correlated systems like $S_1$ and $S_2$ – eg, $p(\lambda_i)$ and $p(\lambda'_i)$ in $Q_s$ or $p(\phi_i)$ and $p(\phi'_i)$ in $Q_c$ – yield correlated results $A^\pm$ and $B^\pm$ without mystery (after Watson 1989).

#5.2. Given that the polarizer orientations **a** and **b** are in 3-space under $Q_s$ and in 2-space (orthogonal to the line of flight) under $Q_c$. Then some understanding of those $A^\pm$ and $B^\pm$ correlations (and the 'collapse' of the wave-function in quantum theory) flows from (14) and (22) with (20):

$$P(B^+ \mid Q_s A^+) - P(B^+ | Q_c A^+) = \tfrac{1}{4}\cos 2s(\pi \pm (\mathbf{a}, \mathbf{b})). \tag{26}$$

#5.3. It is a pleasure to again thank Michel Fodje for many helpful exchanges.

## 6 References


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