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# Quantum Correlations with Independent Photons - Reply to 'Quantum Information with Entangled Photons'

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**Abstract**

*Quantum Rayleigh scattering of single photons rules out coincident detections of the originally entangled, paired photons Correlations between independent states of qubits can easily outperform those calculated with entangled photons. The quantum joint probability for a Bell state can be factorized enabling a local detection of the alleged quantum nonlocality, if it existed.* *© The Author 2024*

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## Introduction

Recent background briefing articles [1-2] reveal significant difficulties in the implementation of practical quantum computers based on the concepts of entangled states and quantum nonlocality-related correlations of detected single photons despite heavy resources having been invested in the last two decades. This is not surprising given the omissions of quantum physical processes and physical contradictions that have been allowed to persist in the professional literature of leading journals.

In a recent review article [3], a range of statements (Sx) can be found:
S1: "Entanglement, a unique quantum mechanical phenomenon, has become a valuable resource without any classical equivalent. The nonlocal and strong correlations present in entangled objects are the backbone of various QIT protocols. Photonic entanglement can now be routinely generated, processed, and measured in quantum optics platforms in laboratory settings." [3; p. 62].
S2: "Entanglement is a quantum-mechanical property, with no classical description, shared by two or multiple

objects. Entanglement gives rise to a stronger-than-classical nonlocal correlation, which can serve as a powerful resource for achieving capabilities that surpass the limitations of classical physics. " [3; p. 63]

S3: "However, it was not until 1964 when Bell translated the mostly philosophical discussion into a setting where experiments could show a clear difference between classical correlations and their quantum counterparts [46], that the testing of the counter-intuitive behavior of entangled systems incentivized experimentalists." [3; p. 65]

S4: "Moving into the 21st century, with pivotal technological advances in entangled-photon sources [56–58] and single-photon detectors [59], tests of Bell's inequalities culminated in a series of unambiguous loophole-free experiments [60–63]." [3; p. 65]

S5 "One well-developed approach for generating optical entanglement is through nonlinear optical processes invoking frequency conversions. Here, the most prominent one is the three-wave mixing process of spontaneous parametric downconversion (SPDC) leading to the generation of photon pairs. " [3; p. 66]

These statements of fundamental aspects of quantum information have been chosen to be proven incorrect from a physical perspective. We begin by listing and referencing in Section 2 elements and aspects of quantum optics which have been either ignored or misinterpreted. Section 3 outlines the shortcomings of Bell inequalities by pointing out that they refer to maximal values of joint probabilities and that quantum correlations do not, in fact, violate these Bell inequalities. The quantum correlation of independent qubits is evaluated in Section 4, while Section 5 reveals the factorization of the quantum correlation of entangled photons by following the concept of wave function collapse after a first measurement. It is found that independent qubits generate stronger correlations between the polarization state vectors on the Poincaré sphere than entangled qubits. Physical aspects are presents in Section 6.

## Rebuttal Elements

Many physical aspects and processes have been omitted from the theory of Quantum Optics for reasons of expediency. Some of these missing elements are listed in this Section and numbered for future reference as Rx.

- Published experimental results in other journals than Physical Review Letters, have reported quantum-strong correlations with independent photons [4-5] based on polarization measurements. These results are consistent with the expansion of the Pauli vector correlation operator [6; p. 422] $\hat{C} = (\boldsymbol{a} \cdot \hat{\sigma})(\boldsymbol{b} \cdot \hat{\sigma})$ leading to an identity operator multiplied by the correlation function, i.e., the operator $\hat{C}$ can be can reduced to [7; Eq. (A6)]:

$$\hat{C} = (\boldsymbol{a} \cdot \hat{\sigma})(\boldsymbol{b} \cdot \hat{\sigma}) = \boldsymbol{a} \cdot \boldsymbol{b}\, \hat{I} + i\, (\boldsymbol{a} \times \boldsymbol{b}) \cdot \hat{\sigma} \quad (1)$$

  where the linear polarization unit vectors a and b identify the orientations of the detecting polarization filters in the Stokes representation, and $\hat{\sigma} = (\hat{\sigma}_1, \hat{\sigma}_2, \hat{\sigma}_3)$ is the Pauli spin vector (with $\hat{\sigma}_2 = i\, \hat{\sigma}_1\, \hat{\sigma}_3$). The presence of the identity operator in Eq. (1) implies that, when the last term vanishes for a linear polarization state, the correlation function is determined by the orientations of the polarization filters, for any type of quantum state, even non-entangled ones [8]. This physical aspect should have been known for the last six decades and should have saved a great deal of misguided research.

- A single photon is deflected from a straight-line propagation in a dielectric medium by the quantum Rayleigh scattering [9]. Groups of identical photons can propagate in a straight-line through stimulated Rayleigh emission [10-11]. The spontaneously emitted photons in the nonlinear crystal undergo parametric amplification forming a group of identical photons. This group of photons can overcome the quantum Rayleigh scattering through quantum Rayleigh stimulated emission (QRStE) [10-11]. The effect of QRStE plays a critical role in creating groups of identical photons in a commonly used dielectric beam splitter as explained in ref. [11]. This physical aspect should have been known for the last four decades and should have saved a great deal of misguided research.

- For maximal values of unity, the Bell parameter $S=\langle a_0\ b_0\rangle+\langle a_0\ b_1\rangle+\langle a_1\ b_0\rangle-\langle a_1\ b_1\rangle$ of eq. (4) in ref. [6] would actually vanish as $\langle a_1\ b_1\rangle=\langle a_0\ b_0\rangle=-1$ and $\langle a_1\ b_0\rangle=\langle a_0\ b_1\rangle=0$ according to the expectation values [6, p. 422] $\langle a_x\, b_y\rangle = -\vec{x}\cdot\vec{y}$ , , for detection settings $\vec{x}_{0;1} \parallel \vec{y}_{0;1}$, and $\vec{x}_{0;1} \perp \vec{y}_{1;0}$ x of the polarization states for coincident detections. Thus, S=0, failing to violate the Clauser-Horne-Shimony-Holt (CHSH) inequality despite involving the strongest quantum correlations. This fact should have rung alarm bells about the irrelevance of the Bell-type inequalities as an indicator of strong correlations between the same order elements of two sequences.

Similarly, as explained in Section 3, the Clauser-Horne (CH) inequality cannot be violated with maximal values of correlations, which fact further disproves the statement that conditional on the property of device independence, "the violation of Bell inequalities can be seen as a detector of entanglement that is robust to any experimental imperfection: as long as a violation is observed, we have the guarantee, independently of any implementation details, that the two systems are entangled."[6, p. 423] In fact, only correlation values of around 0.7, with sign adjustments, violate Bell inequalities, which is identical to the case of 'classical' correlations.

- A sub-section of ref. [6] headlined "More nonlocality with less entanglement" leads one to the anomaly of nonlocality. "Astonishingly, it turns out that in certain cases, and depending on which measure of nonlocality is adopted, less entanglement can lead to more nonlocality." [6, p. 442]. "Remarkably, it turns out that this threshold efficiency can be lowered by considering partially entangled states. This astonishing result was the first demonstration that sometimes less entanglement leads to more nonlocality " [6, p. 464]. This is not surprising because Bell inequalities cannot be violated with maximal correlation values of unity, whether classical or quantum, as explained in the rebuttal point R3. The analysis of quantum correlations for independent photonic qubits is outlined in Section 4.

- The 2015 landmark experiments [12-13] reported a very low probability of coincident detections of a mere 0.0002 (2x10--4) with one setting at each of the two stations, the overall outcomes being fitted with highly non-entangled states of photons, thereby disproving any claim of quantum nonlocality despite the common view [14]. The effect of quantum nonlocality is meant to synchronize the detections recorded at the two locations A and B for polarization-entangled states of photons. In the caption to Fig.1 of [14], on its second page, one reads: "…if both polarizers area aligned along the same direction (a=b), then the results of A and B will be either (+1; +1) or (-1; -1) but never (+1; -1) or (-1; +1.); this is a total correlation as can be determined by measuring the four rates with the fourfold detection circuit." Yet, the quantum correlation is supposed to take place at the level of each pair of entangled photons rather than between averaged values of the two distributions; but such an outcome has never been reported, which fact was ignored in ref. [14].

- From an experimental perspective, the correlation probability of simultaneous detections $p_c\,(a,b)$ is evaluated from a third sequential distribution $v_C\,(a;b)$ calculated as the temporal vector or dot product of the two initial, separately measured, sequences $v(a,x)=\{a_m\}$ and $v(b,y)=\{b_m\}$ leading to $p_c\,(a,b)=(\sum^{N}_{m=1})\ a_m\ \ b_m)/N$ where a,b=0 or 1 are assigned binary values for no-detection or detection of an event, respectively. For any ensemble of measurements, the values of the correlation or conditional joint probability $p_c\,(a,b)$ will depend on the sequential orders of the two separate ensembles at locations A and B. Therefore, as the quantum formalism does not provide any information about those sequential orders, any artificial boundary such as Bell-inequalities are physically meaningless, because for the same values of the local probabilities, $p_A\,(a)$ *and* $p_B\,(b)$, the higher values of $p_c\,(a,b)$ will lead to a violation of the Bell inequality in the classical regime. Bell inequalities can be easily violated with independent photons [4-5], [8].

See Section 3 below for further details undermining the physical significance of Bell inequalities.

- A complete derivation based on the collapse of a Bell state leads to the factorization of the joint probability of detections, with the second local probability being a function of the relative angle between the linear polarization filters. This is presented in Section 5 for the case of one-setting detection of each of two detectors.

- Following the results of [10] that identified dynamic and coherent number states $|\Psi_n(\omega,t)\rangle=(|n(t)\rangle + |n(t)\text{-}1\rangle)/\sqrt{2}$ and recalling the non-Hermicity of the field operators, we find that $\hat{a}\,|n\rangle=\sqrt{n}\,e^{-i\,\varphi})\,|n\text{-}1\rangle$, which provides a complex field amplitude [10], for the time-dependent evolutions of photonic beam fronts. By means of Ehrenfest's theorem – describing the evolution of the expectation value of the photonic field– the phase-d ependent parametric gain or coupling between two optical beams can be calculated [10-11]. Additionally, the quantum regime operations of various types of beam splitters are analysed in the context of quantum Rayleigh emissions [10-11].

- The spatial profile of the intrinsic field of a photon is derived by combining the Maxwell equations and the expectation value of the field operator calculated with the dynamic and coherent number states [10]. The combination of the spatial, longitudinal profile with the random phase of the amplified spontaneously emitted photons provides a physically meaningful explanation for the Hong-Ou-Mandel (HOM) dip of the vanishing coincident count of photons [10].

The first two rebuttal aspects R1 and R2 of this Section disprove and dispel the unique features of entangled photons as presented in statements S1 and S2 of the Introduction. The rebuttal aspects R3 and R4 disprove and dispel the unique features of Bell inequalities as presented in statements S3 and S4. The rebuttal aspects R5, R6 and R7 disprove and dispel the entanglement-based interpretations of the experimental results as presented in statements S4 and S5.

Additional analytic developments will be outlined in the next Sections presenting physically meaningful processes and interactions that undermine the concept of quantum nonlocality.

## Shortcomings of Bell Inequalities

As pointed out in ref. [6], in typical experiments of correlated outputs, the results of the joint probability $p(a,b|x,y)$ of simultaneous or synchronized detections of two sequential ensembles of binary values, do not equal the product of the two separate probabilities of detection $p(a|x)$ and $p(b|y)$ at locations A and B for outcome *a* and *b* corresponding to local settings x and y, respectively, that is:

$$p(a,b|x,y)\neq p(a|x)\;\; p(b|y) \qquad (2)$$

where a,b=0 or 1 are assigned binary values for no-detection or detection of an event, respectively.

In an attempt to explain experimental outcomes obtained with quantum events, it was suggested to convert eq. (2) into an equality of local probabilities [6]:

$$p_f(a,b|x,y;\lambda)= p(a|x;\lambda)\;\; p(b|y;\lambda) \qquad (3)$$

by introducing a "hidden" variable λ whose role would be to create a correlation between the two binary-valued sequences with randomly distributed terms of '0's and '1's, for probabilities of detection $p(a|x;\lambda)$ and $p(b|y;\lambda)$. However, from a physically experimental perspective, the correlation of simultaneous detections is evaluated from a third sequential distribution $v_C(a;b)$ calculated as the vector or dot product of the two initial by introducing a "hidden" variable λ whose role would be to create a correlation between the two binary-valued sequences with randomly distributed terms of '0's and '1's, for probabilities of detection $p(a|x;\lambda)$ and $p(b|y;\lambda)$. However, from a physically experimental perspective, the correlation of simultaneous detections is evaluated from a third sequential distribution $v_C(a;b)$ calculated as the vector or dot product of the two initial sequences $v(a,x)=\{a_m\}$ and $v(b,y)=\{b_m\}$ :

$$\overline{v_C(a;b)} = \overline{v(a)\cdot v(b)} \quad \Rightarrow \quad p_c(a,b) = \frac{1}{N}\sum_{m=1}^{N} a_m\, b_m \qquad (4)$$

with the values of the correlation or joint probability $p_c(a,b|x,y;\lambda)$ ranging above and below the product $p(a|x;\lambda)\ \ p(b|y;\lambda)$. For $p_c(a,b|x,y)> p(a|x)\ \ p(b|y)$ the arbitrary upper limit of eq. (3) renders any further derivation physically irrelevant as it is intentionally limited in value. However, Clauser and Horne, instead of correcting this mistake, derived two Bell-type inequalities [6], [12-13] in the form of functions of probabilities $p_f(a,b|x,y)=\int_\Lambda q(\lambda)\ \ p(a,b|x,y;\lambda)\ \ d\lambda$, with $q(\lambda)$ being the normalized distribution of hidden variables. Those inequalities can be easily violated with classical probabilities $p_c(a,b|x,y)$ of eq. (4) which can be larger than the product of the separate probabilities [4-5]. Later on, neither Aspect, nor Zeilinger noticed the statistical problem of eq. (3), with the landmark experiments of [12] and [13] employing strongly non-entangled photons to violate the Clauser-Horne inequality. The contradictions between theory and experimental results rules out any quantum effect of nonlocality as detailed in the next paragraph.

The quantum correlation function $E_c(1;1|\alpha;\beta)$ for detecting one photon at location A and its pair-photon at location B, is defined in terms of four probabilities between two orthonormal detection-settings at each of the two locations A and B, for eigenvalues +1 or-1, respectively, of local settings α or α' , and β or β' leading to the linear combination of probabilities $P_{ij}$ [15-16]:

$$E_c(1;1|\alpha;\beta)=P_{++}(\alpha;\beta)+ P_{--}(\alpha';\beta')-P_{+-}(\alpha;\beta')-P_{-+}(\alpha';\beta) \qquad (5)$$

where α^'=α+π/2 and β^'=β+π/2 . Fluctuations in the number of detections would give rise to a spread in the values of $P_{ij}$ and $E_c(1;1|\alpha;\beta)$. This correlation function is normally linked to the polarimetric Stokes measurements or the quantum Pauli vector operators and has the same form in both the quantum and classical regimes [8], so that its use in the Clauser-Horne-Shimony-Holt (CHSH) inequality cannot discriminate between quantum and classical outcomes; the quantum counting is sequential whereas the classical counting consists of only one sampling step.

For the CHSH inequality [15-16], the correlation probability is $P_{++}(\alpha;\beta)=N_{++}(\alpha;\beta)/N_{norm}$ where $N_{++}$ is the number of coincident counts of photons and $N_{norm}$ is the number of all coincident detections for all four settings $N_{norm}=N_{++}(\alpha;\beta)+N_{--}(\alpha';\beta')+N_{+-}(\alpha;\beta')+N_{-+}(\alpha';\beta)$. However, this normalization is mathematical because the physical number N_norm=N_in of initiated photon-pairs is very much larger as photons are lost between the source and the photodetectors, for various reasons, thereby throwing doubt about the real statistics. This normalization makes a violation of the CHSC impossible as $N_{++}/N_{in}\ll 0.1$ [12-13].

The Clauser-Horne (CH) inequality has arbitrary values for the two measurement settings, i.e., α and α^' as well as β and β^' are set separately. The CH inequality also contains correlations between '1's and '0's, so that, in terms of binary-valued probabilities p (1,1;α,β) and similar forms, [12-13], the inequality is written as:

$$p(1,1;\alpha,\beta)- p(1,1;\alpha',\beta')\le p(1,0;\alpha,\beta')+p(0,1;\alpha',\beta) \qquad (6)$$

with the normalization factor N_in of initiated events being used. But, as only one term of the four terms is measured in any given run, the linear combination would relate the maximal values on the left-hand side to the minimal values on the right-hand side. With such probabilities for all four terms, the opposite requirements of the inequality for the coincident detections of (1;1) on the left-hand side, and for only one-location detection (1;0) or (0;1) on the right-hand side, make a violation impossible, mathematically, unless arbitrary values are selected from various data sets. In this case, the inequality becomes physically meaningless. For a maximal value of unity for $p\,(1,1;\alpha,\beta)=1$, in order to minimize the right-hand side of eq. (6), the value of $p(1,1;\alpha',\beta')$ should also be unity, which leads to a zero difference on the left-hand side.

## Stronger Quantum Correlations with Independent Qubits

Quantum correlations are evaluated as the expectation values of a product of operators [6], [15]. For the projective operators $\hat{\Pi}(\alpha)=|H_\alpha\rangle\langle H_\alpha|$ and $\hat{\Pi}(\beta)=|H_\beta\rangle\langle H_\beta|$ corresponding to the polarization filters with one detection setting at each of the two locations A and B, respectively, the probability of coincident detections has the form, cf. [6, eq. 13]:

$$p\,(1,1;\alpha,\beta) = \left|\left(\langle\psi_{in}|\hat{\Pi}(\alpha)\right)\left(\hat{\Pi}(\beta)\,|\psi_{in}\rangle\right)\right| = \left|\langle\Phi_\alpha|\Phi_\beta\rangle\right| \tag{7}$$

with $|H_\alpha\rangle$ and $|H_\beta\rangle$ identifying the states of the polarization filters, and $\langle\Phi_\alpha|=\langle\psi_{in}|\hat{\Pi}(\alpha)$ for the Hermitian conjugate state. For the polarization-entangled photons, the outcomes consist of the overlap between two state vectors rotated on the Poincaré sphere and are defined as the correlation function $C(\alpha;\beta)$ between two (mixed) states; by contrast, experimentally, the probability of coincident detections is calculated from the sum of products of overlapping terms, i.e., $p_c\,(a,b)=(\sum_{m=1}^{N} a_m b_m)/N$, as defined in Section 3, and identifies the fraction of simultaneous detections at the level of each quantum event. This discrepancy is part of the disconnect between theory and measurement.

For the basis states $|H\rangle$ and $|V\rangle$ of the shared measurement Hilbert space, the projective amplitudes are $\langle H_\alpha|H_A\rangle=\cos\alpha$, $\langle H_\alpha|\vdash V_A\rangle=\sin\alpha$, $\langle H_\beta|H_B\rangle=\cos\beta$ and $\langle H_\beta|V_B\rangle=\sin\beta$. the correlation function $C(\alpha;\beta)$ of magnitude $|C(\alpha;\beta)|= p\,(1,1;\alpha,\beta)$ between filter polarization states and for independent states of photons $|\psi\_in\rangle$ becomes:

$$C(\alpha;\beta)=\langle\Phi_\alpha|\Phi_\beta\rangle=\langle\psi_{in}|H_\alpha\rangle\langle H_\alpha|H_\beta\rangle\langle H_\beta|\psi_{in}\rangle \tag{8a}$$

$$|\psi_{in}\rangle=(|H\rangle+|V\rangle)/\sqrt{2} \tag{8b}$$

$$|H_\alpha\rangle=\cos\alpha\,|H\rangle+\sin\alpha\,|V\rangle\quad;\quad|H_\beta\rangle=\cos\beta|H\rangle+\sin\beta|V\rangle \tag{8c}$$

$$\begin{aligned}C(\alpha;\beta)&= 0.5[\cos\alpha+\sin\alpha]\,[\cos(\alpha-\beta)]\,[\cos\beta+\sin\beta]=\\ &= 0.5\cos(\alpha-\beta)[\cos(\alpha-\beta)+\sin(\alpha+\beta)]\end{aligned} \tag{8d}$$

This correlation of eq. (8d) is composed of three terms. The projections of the input states onto the respective filters are given by the sum of the sine and cosine functions, on the first line, while the term $\cos(\alpha-\beta)$ indicates the overlap between the two filters in the Jones representation of polarization states. The magnitude of this correlation function or probability of coincident detections can reach a peak of unity for the symmetric case of $\alpha=\beta=\pi/4$ or $\pi/4\pm\pi$, outperforming the coincidence values of 0.5 obtained with entangled states of photons as presented in the following Section 5.

## The Wave Function Collapse Leading to Fctorization of the Quantum Joint Probability

A rigorous derivation based on the formalism of wave function collapse of a maximally entangled state will provide a method to test the concept of quantum nonlocality. If no detection takes place at location A, the projective measurement at location B involves the operator $\hat{\Pi}(\beta)=|H_\beta\rangle\langle H_\beta|$ acting on the initial state

$$|\psi_{AB}\rangle=(|H_A\rangle|V_B\rangle-|V_A\rangle|H_B\rangle)/\sqrt{2} \quad (9)$$

and resulting in the probability of detection

$$P_\beta=\langle\psi_{AB}|\hat{I}_A\otimes|H_\beta\rangle\langle H_\beta|\otimes\hat{I}_A|\psi_{AB}\rangle=(\cos^2\beta+\sin^2\beta)/2=1/2 \quad (10)$$

after setting $\langle H_\beta|H_B\rangle=\cos\beta$ and $\langle H_\beta|V_B\rangle=\sin\beta$ for the projective amplitudes onto the polarization filter. Similarly, for the first detection at location A, i.e., $P_\alpha=1/2$ .

If a first detection takes place at location A involving the projective operator $\hat{\Pi}(\alpha)=|H_\alpha\rangle\langle H_\alpha|$, it will result in an intermediary state for the projective amplitudes $\langle H_\alpha|H_A\rangle=\cos\alpha$ and $\langle H_\alpha|V_A\rangle=\sin\alpha$ , so that the reduced or collapsed wave function $|\psi_{B|A}\rangle$ becomes:

$$|\psi_{B|A}\rangle=|H_\alpha\rangle\langle H_\alpha|\otimes\hat{I}_B|\psi_{AB}\rangle=1/\sqrt{2}\ (\cos\alpha\ |V_B\rangle-\sin\alpha\ |H_B\rangle)|H_\alpha\rangle \quad (11)$$

$$\|\psi_B\rangle=\frac{|\psi_{B|A}\rangle}{\sqrt{\mathbb{N}}}=\frac{|H_\alpha\rangle\langle H_\alpha|\otimes\hat{I}_B|\psi_{AB}\rangle}{\sqrt{\mathbb{N}}} \quad (12)$$

where $|\psi_B\rangle$ denotes the normalised wave function for the calculation of the detection probability at location B, conditional on a detection at location A. The normalization factor N=1/2 for the collapsed wave function $|\psi_{B|A}\rangle$ corresponds to the probability of detection $P_\alpha$ for the first measurement, and after substituting for $|\psi_B\rangle$ from eq. (12) we have:

$$P_\alpha=\langle\psi_{AB}|\hat{I}_B\otimes|H_\alpha\rangle\langle H_\alpha|\otimes\hat{I}_B|\psi_{AB}\rangle=|\langle H_\alpha|\psi_{AB}\rangle|^2=N\langle\psi_B|\psi_B\rangle=1/2 \quad (13)$$

Based on the normalized state $|\psi_B\rangle$, the probability of detection at location B following a detection at location A, becomes in this case, for a projective measurement:

$$P_{\beta|\alpha}=\langle\psi_B|H_\beta\rangle\langle H_\beta|\psi_B\rangle=|\cos\alpha\ \sin\beta-\sin\alpha\ \cos\beta|^2=\sin^2(\beta-\alpha) \quad (14)$$

This result which can be found in [15, Sec.19.5] implies that for $\beta-\alpha=\pm\pi/2$, regardless of the values of $\beta$ or $\alpha$ , the local probability of detection could peak at unity. This theoretical outcome is easily testable experimentally for direct evidence of a quantum nonlocal effect influencing the second measurement after the wave function collapse. But this has never been done either because of the quantum Rayleigh scattering [9] of a single-photon and/or the non-existence of such a nonlocal effect. The product of the local probabilities of eqs. (13) and (14) equals the expression of the joint probability P_αβ for simultaneous detections at both locations A and B, that is:

$$P_{\alpha\beta}=\left|\langle H_\beta|\langle H_\alpha|\frac{|\psi_{AB}\rangle}{\sqrt{P_\alpha}}\right|^2 P_\alpha=\left|\langle H_\beta|\psi_B\rangle\right|^2 P_\alpha=P_{\beta|\alpha}P_\alpha \quad (15a)$$

$$P_{\alpha\beta}=\langle\psi_{AB}|H_\alpha\rangle|H_\beta\rangle\otimes\langle H_\beta|\langle H_\alpha|\psi_{AB}\rangle=0.5\ \sin^2(\beta-\alpha) \quad (15b)$$

$$P_{\alpha\beta}=P_\alpha P_{\beta|\alpha}\leq P_\alpha P_\beta \quad (15c)$$

after inserting from Eqs. (12) and (14) in the equality (15a). The equality (15b) provides a direct calculation of the joint probability, confirming the validity of the derivation. With the conditional probability of local detection $P_{\beta|\alpha}$ being, mathematically, lower than, or at best, equal to the local probability of detection $P_\beta$ in the absence of a first detection, i.e., $P_{\beta|\alpha}\leq P_\beta$, the formalism of wave function collapse gives rise to a factorization of local probabilities and imposes an upper bound on the quantum joint probability, in clear contradiction to the conventional assumption [15, p.538]. This formalism delivers average values of the ensembles rather than correlation between the sequential orders of the detections. The possibility of factorizing the quantum probability for joint events as in (15a) is identical to the classical case of joint probabilities with the second local probability being conditioned on a first detection. This strong similarity between the classical and quantum joint probabilities renders the local condition of separability [6], [15] irrelevant for the derivation of Bell inequalities.

### The Flaws of the Quantum Nonlocality Interpretation of Experiments

For the two polarized photons shown in the inset to Fig. 1 of [14] “quantum mechanics predicts that the polarization measurements performed at the two distant stations will be strongly correlated.” Yet, quantum-strong correlations can also be achieved with independent photons or classical systems [4-5], [8].

Another quotation of interest from [14] is: “In what are now known as Bell’s inequalities, he showed that, for any local realist formalism, there exist limits on the predicted correlations.” Once again, as pointed out above, Bell inequalities can be violated with expectation values from independent and multi-photon states [4-5], [8], but cannot be violated with maximal values of unity correlation, contradicting their purpose.

At least three critical elements have been ignored in the interpretations of experimental results alleging proof of quantum nonlocality: 1) the quantum Rayleigh scattering involving photon-dipole interactions in a dielectric medium [10-11], which prevents a single photon from propagating in a straight-line, thereby obstructing the synchronized detections of initially paired-photons; 2) the unavoidable parametric amplification of the spontaneously emitted photons in the nonlinear crystal of the original source [10-11]; and 3) the experimental evidence of quantum-strong correlations between polarization states or statistical ensembles of multi-photon, independent states [4-5].

The theoretical concept of photonic quantum nonlocality cannot be implemented physically because of the quantum Rayleigh scattering of single photons [9]. Landmark experiments [12-13] reported that measured outcomes were fitted with quantum states possessing a dominant component of non-entangled photons, thereby contradicting their own claim of quantum nonlocality. With probabilities of joint detections lower than 0.001, the alleged quantum nonlocality cannot be classified as a resource for developing quantum computing devices [1-2], despite recent publicity.

All the experimental evidence indicates the absence of a quantum effect between two simultaneously measured single and entangled photons because of the quantum Rayleigh scattering of single photons. The theoretical quantum joint probability for entangled photons is limited by an upper value of 0.5, whereas the correlation between independent qubits on the Poincaré sphere can exceed 0.5 as shown in Section 4. Equally, the classical correlation coefficient between two sequences of arbitrarily distributed binary values can be larger than 0.5, calculated as the sum of same order, overlapping, product components of '1' or '0' as explained in Section 3.

The quantum reality of independent states of photons takes precedence over the quantum nonlocality of statistically mixed quantum states by delivering stronger quantum correlations as explained in Section 4. The mixed states are time- and space independent and can be used at anytime, anywhere and in any context regardless of the physical context and circumstances. Thus, discarding critically informative aspects of the photonic systems being probed leads to the need for ‘counter-intuitive’ explanations such as the quantum nonlocality phenomenon which would be based on the concept of wave function collapse, leading to the factorization of the joint probability of simultaneous detections which would be testable locally. Once again, no experimental evidence of these features has been reported.

Consequently, the physical reality as promoted by Einstein prevails over the mythical quantum nonlocality of Bohr, if only because a single photon will be scattered about in a dielectric medium by the quantum Rayleigh scattering.

## Conclusions

A long series of physical errors, some of which stemming from disregard for scientific methodology, have been covered up over the last six decades. An arbitrarily defined probability threshold which, allegedly, can only be violated by quantum correlations was repeatedly proven to be physically incorrect. Experimental outcomes purporting to prove the role of polarization-entangled photons were, in fact, modelled with a high level of non-entangled states.

No explanation is provided in ref. [3] about the physically meaningful process of Rayleigh scattering of single photons which prevents synchronized detections of the original pair of entangled photons. The absence of such experimental evidence is consistent with the analysis based on the concept of wave function collapse leading to the factorization of the quantum joint probability. This, in turn, should enable a local determination of the alleged quantum nonlocality, which has never been reported.

Therefore, Gisin's statement [17] that "…a violation of a Bell inequality proves that no future theory can satisfy the locality condition" is physically unsubstantiated given the evidence to the contrary presented in Sections 2 , 3 and 4 above, and references [4-5].

Taking into consideration all the flaws and shortcomings of the theoretical claims and experimental outcomes, it is obvious to any impartial physicist that no evidence of a nonlocal quantum effect can be identified. The 2022 Nobel Prize Committee intentionally disregarded the various rebuttals and refutations of the concept of quantum nonlocality in line with the editorial policy of journals such as Physical Review Letters and Physical Review A which knock back without consideration any well-substantiated article outlining the physical reality of Einstein.

For further details see ref. [18].

**Data Availability Statement:** The physical analysis of this article is based on published measurement data as reported in the references listed below. This article provides physically meaningful interpretations of available data but does not generate data of its own.

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