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# Physical Contradictions Ruling out Photonic Quantum Nonlocality

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# Physical Contradictions Ruling out Photonic Quantum Nonlocality

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*Abstract-* A series of physical contradictions can be identified in an opinion article published in December 2015 (A. Aspect, "Closing the Door on Einstein and Bohr's Quantum Debate," Physics *8*, 123, 2015) claiming definitive proof of quantum nonlocality based on entangled pairs of photons. For example, experimental results published simultaneously in Physical Review Letters (250401 and 250402, 2015) were theoretically fitted with distributions containing a dominant unentangled component, contradicting the need for maximally entangled states underpinning quantum nonlocality. Such contradictions were ignored by the 2022 Nobel Prize Committee raising doubts about the validity of their decision.

## I. Introduction

Over the last two decades, large amounts of resources have been invested in the research and development of quantum computing based on the concept of quantum nonlocality. Yet, no such functional or operational device is expected in the near future. Nevertheless, photonic quantum nonlocality – despite being substantially rebutted in the professional literature (see references 1-8 below for a short list) – has been the subject of the 2022 Nobel Prize Committee. This approach may actually lead to a dead end.

While the three physicists deserve credit for performing experiments with entangled photons, their interpretations of the experiments do **not** stand up to physical scrutiny in so far as the following four aspects are concerned.

1. *Entangled Pairs of Photons–* Quantum entanglement of states or photons is the consequence of a common past interaction between states or photons and those properties generated in the common interaction can be carried away from the position and time of that interaction. A single photon cannot propagate in a straight-line inside a dielectric medium because of the quantum Rayleigh scattering associated with photon-dipole interactions. Groups of photons are created through parametric amplification in the nonlinear crystal in which spontaneous emissions first occur. Such a group of photons will maintain a straight line of propagation by recapturing an absorbed photon through stimulated Rayleigh emission – see references 7 and 9.

The assumption that spontaneously emitted, parametrically down-converted individual photons cannot be amplified in the originating crystal because of a low level of pump power would, in fact, prevent any sustained emission in the direction of phase-matching condition because of the Rayleigh spontaneous scattering. For details, see references 7 and 9.

2. *Quantum Nonlocality upon Sequential Measurements–* Quantum nonlocality is claimed to influence the measurement of the polarization state of one photon at location B, which is paired with another photon measured at location A. The two photons are said to be components of the same entangled state. Maximally entangled states, represented in the same frame of coordinates of horizontal and vertical polarizations, would deliver the strongest correlation values between separate measurements of polarization states recorded at the two locations A and B.

If a collapse of the wave function is to take place for entangled photons upon detection of a photon at either location, then the two separate measurements do not coincide. In this case, a local measurement vanishes for the maximally entangled Bell states– see Appendix A below. This leads to a physical contradiction as local experimental outcomes determine the state of polarization to be compared with its pair quantum state. This overlooked feature of maximally entangled Bell states renders them incompatible with the polarimetric measurements carried out to determine the state of polarization of photons, thereby explaining the experimental results of reference 10 which were obtained with independent photons. The wave function collapse brings about a product state as part of a time-dependent partial ensemble of measurements.

As already mentioned above, the rebuttal of the concept of quantum nonlocality has seen a growing body of analytic work which the legacy journals have chosen to ignore, e.g. references 1-8. In references 11 and 12, the optimal experimental states identified in their equations (2) contain a large unentangled component which provides the non-zero values for the correlation function – see Appendix B for details. In reference 11, all probabilities of detecting an event is lower than $10^{-3}$. With such a small probability (<<1%) it is not justified to classify the random events as a quantum physical process that is a resource for quantum computing.

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3. *Correlation Functions*– Maximally entangled states, represented in the same frame of coordinates of horizontal and vertical polarizations, would deliver the strongest correlation values of the correlation function $E_c = cos\ [2\,(\theta_A - \theta_B)]$, for identical inputs to the two separate apparatuses, with the polarization filters rotated by an angle $\theta_A\ or\ \theta_B$ , respectively, from the horizontal axis. However, quantum-strong correlations with independent photons have been demonstrated experimentally (see reference 10) but ignored by legacy journals because they did not fit in with the theory of quantum nonlocality. The same correlation function $E_c = cos\ [2\,(\theta_A - \theta_B)]$ is obtained 'classically', as a result of the overlap of two polarization Stokes vectors of the polarization filters on the Poincaré sphere– see Appendix B for details. The Stokes parameters correspond to the expectation values of the Pauli spin operators– see reference 8.

Polarimetric measurements made in the quantum regime are based on the Pauli spin operators whose expectation values are displayed on the Poincaré sphere. However, these operators act on the state of polarization regardless of the number of photons carried by the radiation mode, instantaneously. The correlation functions needed to evaluate various Bell-type inequalities take the same form in both the quantum and classical regimes, and correspond to the overlap of the polarization states in the Stokes representation – see reference 8.

4. *Bell-type Inequalities*– Quantum measurements violating Bell-type inequalities are supposed to be based on entangled states of single photons and prove the existence of quantum nonlocality. But the violations of inequalities rely on the correlation functions of the two ensembles of measurements as opposed to the same pair of photons, that is, the correlations are obtained as a result of a numerical comparison and are not a physical interaction. The photonic properties were carried away from the space and time of the original interaction, with the *measurement identifying* which of the two photons possessed the respective states of polarization.

Bell-type inequalities can also be violated classically because the same correlation function is derived for both the quantum and classical regimes, as explained in the previous section 3. Thus, from a technological perspective, functional devices needed for strong correlations between two separate outputs can be achieved with multiple photons, thereby obviating the need for complicated and expensive single photon sources and photodetectors.

In conclusion, a range of considerations rebut the concept of quantum nonlocality whereby a measurement of an entangled photon influences the outcome of a pair-measurement at another location. Quantum-strong correlations which are needed for quantum data processing, can be produced by means of uncorrelated and multiphoton states as well as 'classically' by means of Stokes parameters on the Poincaré sphere. In this way the complicated and expensive single-photon sources and photodetectors become unnecessary.

## II. Appendix A -Contradictory Statements

If a collapse of the wave function is to take place for entangled photons upon detection of a photon at either location, then the two separate measurements do not coincide. In this case, a local measurement vanishes for the maximally entangled Bell states, e. g. $|\psi_{AB}\rangle = (|H\rangle_A\,|H\rangle_B + |V\rangle_A|V\rangle_B)/\sqrt{2}$, that is, $\langle\psi_{AB}\,|\,\hat{\sigma}_A \otimes \hat{I}_B\,|\psi_{AB}\rangle = 0$ , with $\hat{I}_B = |\,H\rangle\langle\,H| + |\,V\,\rangle\langle\,V|$ being the identity operator, and the projecting Pauli operators are in this case $\hat{\sigma}_1\ =\ |\,H\,\rangle\langle\,V\,| + |\,V\,\rangle\langle\,H\,|$ and $\hat{\sigma}_3\ =\ |H\rangle\langle H| - |V\rangle\langle V|$. Thus, a physical contradiction arises as local experimental outcomes determine the mixed quantum state of polarization of the ensemble to be compared with its pair quantum state. However, the experimental results of reference 10 which were obtained with independent photons clearly indicate the possibility of obtaining quantum-strong correlations without entangled photons as explained in reference 8.

The mixed quantum state $|\psi_{AB}\rangle$ is space- and time-independent and considered to be a global state which can be used in any context, anywhere, and at any time. Nevertheless, the Hilbert spaces of the two photons move away from each other and do not spatially overlap, so that any composite Hilbert space is *mathematically* generated by means of a tensor product at a third location where the comparison of data is performed. Even so, the absence of a Hamiltonian of interaction renders any suggestion of a mutual influence physically impossible– see reference 1.

Furthermore, the experimental results of references 11 and 12 were measured with a low level of entanglement, with the reported mixed states having one component much larger than the other, thereby allowing for measurements of unentangled product states. From equations (2) of both references, their experimental optimal ratios of the two amplitudes are 2.9 and 0.961/0.276, respectively.

Another glaring contradiction of the quantum nonlocality interpretation can be found in reference 13. In the caption to Fig.1, 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".

This statement first deals with single, individual events but in the second part it mentions "rates" which

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apply to ensemble of measurements (as degree or comparative extent of action or procedure). Now, if it is possible, with entangled photons, to have 100% correlation at the level of individual events, then one could easily carry out a short series of measurements to find simultaneous detections and prove directly the existence of quantum nonlocality, rather than use, indirectly, Bell-type inequalities to claim it from correlations of ensembles. Ensemble distributions also cover non-simultaneous single detections that are taken to be simultaneous in order to reach the 100% correlation value.

Ensembles of two separate measurements lead to two sets of probabilities. Correlations between distributions of ensemble probabilities are calculated as the expectation value of the correlation operator $\hat{C} = \hat{\sigma}_A \otimes \hat{\sigma}_B$ to be $E_c = cos\ [2\,(\theta_A - \theta_B)]$ as opposed to probabilities of single, individual events $P_{A\ or\ B} = cos^2\,\theta$, identical for both locations with $E_c = 1$.

For example, if one in ten photons is detected, then, for entangled photons, the two separate detections should happen simultaneously with a ratio of 1:10, as claimed with quantum nonlocality. This would allow a direct measurement and demonstration of quantum nonlocality without the need for Bell-type inequalities that involve ensembles of measurements. But this cannot be done because a single photon is diverted by the quantum Rayleigh scattering in a dielectric medium from a straight-line propagation. Therefore, no quantum nonlocality has been demonstrated in so far as single photons are concerned.

## III. Appendix B - General Correlation Functions

The correlation function is a *numerical* calculation as opposed to a physical interaction. Thus, the numerical comparison of the data sets is carried out at a third location *C* where the reference system of coordinates is located for comparison or correlation calculations of the two sets of measured data, and does not require physical overlap of the observables whose operators are aligned with the system of coordinates of the measurement Hilbert space onto which the detected state vectors are mapped. In this case, the correlation operator $\hat{C} = \hat{\sigma}_A \otimes \hat{\sigma}_B$ can be reduced to [14; Eq. (A6)]:

$$\hat{C} = (\boldsymbol{a}\cdot\hat{\sigma})(\boldsymbol{b}\cdot\hat{\sigma}) = \boldsymbol{a}\cdot\boldsymbol{b}\hat{I} + i\,(\,\boldsymbol{a}\times\boldsymbol{b}\,)\cdot\hat{\sigma} \qquad \text{(B1)}$$

where the polarization vectors $\boldsymbol{a}$ and $\boldsymbol{b}$ identify the orientation 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. (B1) implies that, when the last term vanishes for a linear polarization state, the correlation function is determined by the orientations of the polarization filters. This can be easily done with independent and linearly polarized states.

In order to emphasize the role played by independent states of photons, these states $|\,\psi_k\rangle$ will be expanded in terms of the polarization eigenstates of the reference system of coordinates that will also define the joint Poincaré sphere. The states are, with *k* = *A* or *B*:

$$|\,\psi_k\rangle = cos\,\varphi_k\,|x\rangle\ + sin\,\varphi_k\,|y\rangle \qquad \text{(B2)}$$

for two different angles $\varphi_A$ and $\varphi_B$ , relative to the *x* – axis of reference in the measurement-related Hilbert space onto which the detected states are projected by the measuring detectors *A* and *B*, respectively.

The polarization operator $\hat{\sigma}$ projects the incoming states onto the measurement Hilbert space for comparison of the two separate data sets. The polarization measurement operators of $\hat{\sigma}(\theta_k) = \sin\,(\,2\theta_k)\,\hat{\sigma}_1 + cos(2\theta_k)\,\hat{\sigma}_3$ produce the output states

$$|\Phi_k\rangle = \sin\,(\,2\theta_k)\,\hat{\sigma}_1\,|\,\psi_k\rangle + cos(2\theta_k)\,\hat{\sigma}_3\,|\,\psi_k\rangle \qquad \text{(B3)}$$

Which, analogously to the overlapping inner product of two state vectors, lead to the correlation function of

$$E_c = \langle\Phi_A\,|\,\Phi_B\rangle = cos[2\,(\theta_A - \theta_B) - (\varphi_A - \varphi_B)] \qquad \text{(B4)}$$

Recalling that the phases $\varphi_k$ are set in the Jones representation, this result links the overlap of the Jones vectors to the correlation of the corresponding Stokes vectors $\vec{s}_{A\ or\ B}$ on the Poincaré sphere where the angle $2\varphi_k$ applies, that is:

$$E_c = \vec{s}_A\cdot\vec{s}_B = \cos 2\,(\triangle\,\phi) \qquad \text{(B5)}$$

$$\triangle\,\phi = \theta_A - \theta_B - (\varphi_A - \varphi_B)$$

The quantum correlation function of Eq. (B5) between two independent states of polarized photons is equivalent to the overlap of their Stokes vectors on the joint Poincaré sphere of the measurement Hilbert space. Quantum-strong correlation are possible with independent states of photons because the source of the correlation is the polarization states of the detecting filters or analyzers, making any claim of quantum nonlocality unnecessary.

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