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Peer Review

# Review of: "Aristotle, Heisenberg, and the Non-Locality and Non-Temporality of a Single Photon"

**Arkady Bolotin**[1]

1. Ben-Gurion University of the Negev, Israel

This research article explores the interaction of energy exchange by photons through the lens of Aristotelian philosophy and quantum mechanics. The main points of the paper include:

· **Aristotelian Framework in Physics:** The author uses Aristotelian philosophy to analyse the behaviour of photons, emphasizing change and movement as continuous processes rather than discrete events.

· **Heisenberg Uncertainty Principle (HUP):** The discussion incorporates the HUP, showing how uncertainty in energy and time affects our understanding of photon behaviour.

· **Gedanken Experiments on Single Photons:** Several thought experiments are presented to illustrate how the trajectory of photons is influenced by non-local and non-temporal correlations.

· **Non-Locality and Non-Temporality of Photons:** The findings suggest that a photon's trajectory is influenced by its final state, even though it is spatially and temporally separated from its initial state.

· **Experimental Support from Optical Micro-resonators:** The study examines experimental and numerical work on optical micro-resonators to assess the validity of Maxwell's equations and confirm theoretical predictions.

· **Philosophical and Physical Insights:** The results imply that photons are subject to non-temporal processes, meaning their behaviour is determined holistically rather than just by initial conditions.

The paper contends that photons display characteristics that challenge the foundations of classical physics, proposing that their motion may be more effectively interpreted through a philosophical perspective that accommodates influences extending beyond direct causality.

However, the paper presents several problematic aspects that cast doubt on the validity of its conclusions.

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First, in discussing the peculiar properties of a photon, the author employs the relation $\Delta E \Delta t \geq \hbar/2$, interpreting  as uncertainties in energy and time, respectively. However, this interpretation is, at the very least, contentious. This stems from the fact that time does not appear as an operator in Schrödinger's equation but solely as a parameter. Consequently, time must commute with every operator of the system under observation, including its Hamiltonian. Therefore, quantum theory principles provide no inherent reason why the energy of a system cannot be measured within an arbitrarily short time interval. In other words, $\Delta E$ and $\Delta t$ cannot be treated as uncertainties in energy and time in the same manner as uncertainties between non-commutative physical variables.

Second, the author's argument relies on three principal ideas:

1. The coherence length of a photon remains unchanged during the complete lifetime from emission to absorption.
2. The coherence length is dependent not only on the source properties but on the characteristics of the whole trajectory.
3. The trajectory of a photon is dependent on the coherence length.

Regarding the first idea: This is not necessarily accurate. The coherence length of a photon can be affected by various factors during its travel from emission to absorption. While initially determined by the spectral characteristics of the source, environmental factors such as dispersion, scattering, and diffraction can alter the coherence length during propagation. For example, in long-distance transmission systems, coherence length may decrease due to such effects. Therefore, coherence length is not a fixed property of the photon throughout its lifetime.

The second idea is correct; however, the third idea is flawed. The trajectory of a photon is not directly dependent on its coherence length. Coherence length describes the wave-like properties of light, specifically the distance over which the wave's phase remains consistent and predictable. Conversely, a photon's trajectory is shaped by factors like the geometry of the system, interactions with matter, and external fields.

That said, coherence length can indirectly influence phenomena such as interference and diffraction, which are tied to the wave-like behaviour of photons. For instance, in interferometric setups, coherence length determines the maximum path difference over which interference patterns can occur, which may impact how a photon's trajectory is interpreted in such scenarios.

Now, turning to the author's clarification on whether a photon constitutes an object of physical reality:


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The nature of a photon as a physical reality is a subject of ongoing philosophical and scientific discourse. In physics, photons are defined as quantum particles—or quanta—of the electromagnetic field, exhibiting both particle-like and wave-like behaviours depending on the context of observation. This duality is a foundational principle of quantum mechanics.

From a practical perspective, photons are considered real entities due to the experimental evidence supporting their existence and properties, as demonstrated in phenomena such as the photoelectric effect, Compton scattering, and quantum entanglement. Nevertheless, some interpretations of quantum mechanics challenge the classical notion of "objects," portraying photons as excitations or localized disturbances within the electromagnetic field rather than discrete objects.

Therefore, while the concept of the photon is indispensable for describing and predicting physical phenomena, its precise nature—whether as a concrete entity or an abstract construct—remains an open and nuanced question.

Finally, addressing the notion that a single photon possesses a nontemporal character: Photons, being massless particles, propagate at the speed of light, and within the framework of relativity, time does not progress for objects moving at light speed. This gives rise to the concept that photons exist in a state where time is not a defining factor for their existence—a notion commonly referred to as "nontemporality."

However, it is crucial to recognize that this concept remains a theoretical abstraction rather than a directly observable property, as photons interact with spacetime and other particles in ways that are measurable in a temporal context.

While the non-local behaviour of photons has been conclusively demonstrated through quantum mechanics experiments (including those based on quantum entanglement and Bell's theorem), experimental confirmation of "non-temporal behaviour" is less direct and often relies on interpretations within the domains of quantum mechanics and relativity.

## Declarations

**Potential competing interests:** No potential competing interests to declare.