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Peer Review

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

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In his motivating article, the author, Professor Driessen, writes:

"As a result of the discussion, one has to accept that the photon trajectory is causally influenced by the final state, which is separated in time and space from the initial state: non-locality and non-temporality."

If I understand correctly, according to Prof. Driessen, in the physical example dealing with a photon, there might be non-local interactions where causes and events are related in such a way that "faster than light correlations are involved or action on a distance."

Moreover, "non-temporality means that events in the future light cone have a certain influence on the present state of the origin… In the case of non-temporality, faster than light effects would not solve the occurrence of these striking correlations."

Certainly, these phenomena and the corresponding results are peculiar. It seems like a paradox of the theory. However, to say that the photon trajectory is causally influenced by the final state makes sense in a deterministic vision of physical reality: Cause and effect link the past with the future and vice versa. Starting from the initial state, the photon trajectory and its final state are physically determined, and vice versa, starting from the final state. There are no problems in this case.

The main difficulty I see when dealing with the physical system involving a single particle considered by the author, with the additional assumption that it requires to be described with quantum mechanics, is that the theory actually does not deal with a single particle but involves the properties of many particles and their statistical behavior. In the double-slit experiment with electrons, the wave-like pattern observed is that of many particles interfering with the slit. If a single electron is used, we can observe no more than a single spot on the screen produced by the particle. The same holds true if the particle is a

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photon. To have an interference pattern with a single particle, the theory needs to extend to the single particle the statistical wave properties of the ensemble. Then, the particle is now a wave that can even interfere with itself. Still, the particle's attributes remain unknown and inaccessible. Perhaps, the reader can benefit if the author discusses and clarifies these aspects in relation to the behavior of a single photon.

The work of Prof. Driessen is vast and complex, and it is hard for me to provide a judgment. I can only ask some questions that perhaps can help the reader to better understand the article if the author thinks it is worth improving the presentation of the problem.

Let us consider some technical details of the approach of the author, who writes the energy relation $E=h\nu$ and the Heisenberg Uncertainty Principle (HUP) relation as

$$\Delta v \cdot \Delta t \geq 1/(4\pi) \qquad (3)$$

where v is the photon frequency.

Supposedly, Δv represents the uncertainty of the measurement of the frequency v in the time interval Δt.

Then, Prof. Driessen considers the bandwidth $\Delta\nu$ of the full-width-at-half-maximum (FWHM) of the pulse spectrum and estimates that Eq (3) can be rewritten as

$$\Delta v \cdot \Delta t = 5/(4\pi) \qquad (4).$$

I have a question here for Prof. Driessen. In the HUP of Eq (3), Δv is related to a single photon, while in (4) Δv is that of a bandwidth of a statistical ensemble of many photons. Am I correct? Then, in my opinion, the quantity Δv in Eq (4) does not represent the uncertainty of the measurement of the frequency v of a single photon. In other words, Eq (4) refers to average values of some physical quantities of an ensemble of photons and is not necessarily related to the uncertainties of the physical quantities indicated in Eq (3) related to the HUP of a single photon.

In principle, the wave properties of an ensemble are not necessarily the same as those of an individual particle. It may be just an assumption of the theory. To assume that they are the same is probably what leads to the paradoxes pointed out by Prof. Driessen.

Furthermore, Prof. Driessen states that

"...In the HUP, as formulated in Eq. (4), the uncertainty in time Δt can also be expressed as the uncertainty in the coherence length $l_c = c\Delta t$. It is referred to as the pulse duration or the FWHM of the source."

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Actually, the expression l_c= cΔt represents the classical optic relation between the distance traversed with speed c by a light particle in the time interval Δt. I am not sure the uncertainty in the length can be related to an uncertainty in time. Thus, I suspect that the relation l_c= cΔt has nothing to do with the HUP or quantum mechanics. In fact, from the HUP written as $\Delta p\cdot\Delta l \geq h/(4\pi)$, the uncertainty in the length, say Δl_c, can be linked to the uncertainty Δp of the momentum p = E/ of the photon, not to Δt.

Other statements that may need to be proved or supported theoretically and empirically are:

a. "i. the coherence length of a photon remains unchanged during the complete lifetime from emission to absorption.

ii. the coherence length is dependent not only on the source properties but on the characteristics of the whole trajectory.

iii. the trajectory of a photon is dependent on the coherence length."

b. "The consequences are dramatic, as photons of astronomical light sources connect events separated in space and time by billions of light-years and billions of years, respectively."

Coherence of electromagnetic waves is meant statistically and refers to properties and similarities of a wave in relation to another wave (in relation to the phase of the waves, for example). Coherent waves, such as standing waves, may be set up in an interferometer. Perhaps, the Author could explain or clarify what he means by coherency when referring to a single photon. Otherwise, it seems hard to believe that the properties of statement a) hold true for a single photon, regardless of whether it comes from the astronomical light sources mentioned in b).

Nevertheless, skipping technicalities, I fully agree with the Author that the comment of Heisenberg about the probability wave of Bohr, Kramers, Slater is definitely clarifying at the metalevel:

"It meant a tendency for something. It was a quantitative version of the old concept of potentia in Aristotelian philosophy. It introduced something standing in the middle between the idea of an event and the actual event, a strange kind of physical reality just in the middle between possibility and reality."

In conclusion, I find better agreement with the Author on philosophical concepts rather than on technical details. Perhaps, the essence of quantum theory is meant to be understood metaphysically rather than physically.

Best wishes to the Author for his interesting research.

Declarations

Potential competing interests: No potential competing interests to declare.

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