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On possible origin of photon correlations

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Abstract

We present a hypothesis explaining quantum non-locality in the experiments with photons (EPR, delay choice, etc.) by the following argument: in a *laboratory* reference frame the photon travelling duration is finite, however its travelling *proper* duration (in vacuum) equals to zero. In the last case one can consider as simultaneous ones the events separated by an arbitrary distance in a laboratory reference frame; so, the non-locality property turns out to be relative one and can be explained like the known twin paradox in the Relativity. The arguments are proposed in order to expand this hypothesis on massive quantum particles.

1. Introduction

In the modern physics since 1935 one discusses the non-local influence between a pair of quantum particles that initially have had interacted but then became arbitrary distant from one another **[EPR, 1935].** Schrödinger called such phenomenon as *entanglement* **[Schrödinger, 1935, 1936]**. It is specified by the fact that before a measurement event a state of both EPR-partners is not well-defined (it presents a superposition of possible states), however, after the measurement (and dependently on the measurement arrangement) the partner states turn out to be correlated independently on a distance between them. The fact is confirmed by the numerous experiments starting from the work [**Aspect, 2000]**.

It seems to be contradictory to the Special Relativity (SR) which states that an energy and information superluminal transport is impossible (non-signaling condition). J. Bell wrote: “The correlations seem to cry out for an explanation, and we don't have one*!”* **[Bell, 1990].**

We intend below to explain the correlations emergence by considering the photon’s properties in SR. It is motivated because a photon has the speed of light. However, for an arbitrary pair of particles with a mass we have to introduce an additional hypothesis that between any entangled pair the entanglement interaction also propagates with the speed of light in vacuum.

2. A laboratory reference frame vs moving one

In physics one usually calls a (conditionally) immovable reference frame associated with the observer as *laboratory* one. As it is known, in SR a distance length and time duration between two 4-events in a lab reference frame are not the same as in a moving one. This means that in the moving reference frame distances and durations became shorter, however their fraction is invariant.

For example, so called “twin paradox” is investigated enough and widely described in literature in which some astronaut after travelling through Space with a very large velocity (near to the speed of light) and returning to Earth reveals that his own advance in age is strongly less than this one of his twin who did not leave Earth[1].

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[1] Note, the astronaut’s way was not rectilinear, because of that the 4D (timespatial) interval in his reference frame will not the same as in the terrestrial one (due to difference of durations when he returned at the same 3D point).

3. Wheeler’s “galactical” paradox

J. Wheeler proposed **[Wheeler, 1984]** such the gedanken experiment. Let a distant quasar Q to emit a photon that travels to Earth during billions years (Fig.1). Due to the gravitational lens action of galaxy G, the photon generated from a quasar (Q) has two (or more) possible paths to reach the telescope T entry on Earth.

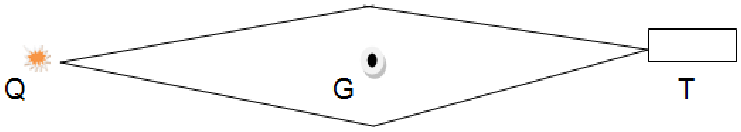

Figure 1. Due to the gravitational lens action of galaxy G, the photon generated from a quasar (Q) has two (or more) possible paths to reach the telescope T on Earth at the entry of which there is a Mach-Zehnder interferometer.

At the entry of telescope T there is a Mach-Zehnder interferometer. The additional half-silvered mirror of the interferometer can be inserted or removed at will. When the mirror is removed, the detectors allow one to determine through which path the photon propagated, so the photon behaves as a particle. Contrary, when the mirror is inserted, detection probabilities of the two detectors depend on the length difference between the two arms, and one can observe the interference pattern. “Given the distance between the quasar and the receptor (billions of light years), the choice can be made long after the light’s entry into the interferometer” **[Wheeler, 1984]**.

Note, Wheeler analyses the situation exclusively in the lab reference frame. However, it is interestingly to consider the situation “from photon’s viewpoint”[2]. As SR states, there is not a time duration nor space distance for a photon propagating, they are equal to zero from “its viewpoint”. So, for such photon two time points – start from the quasar Q and arrival at the telescope T when it passes (or does not pass) trough the beamsplitter – present the same time point from “photon’s viewpoint”. Thus, any contradiction is absent in the fact that one decides whether the photon shall have come by one route or by both routes after it has already done its travel, because the total photon travelling duration is equal to zero!

In SR we see using implicit arguments that such paradox is not only possible (the photon emission and absorption are simultaneous from “its viewpoint”), but even is inevitable as well as the twin paradox is.

In the widely known paper **[Wheeler and Feynman, 1945]** the very deep idea was reproduced from **[Tetrode, 1922]**:

> "The sun would not radiate if it were alone in space and no other bodies could absorb its radiation. <...> If for example I observed through my telescope yesterday evening that star which let us say is 100 light years away, then not only did I know that the light which it allowed to reach my eye was emitted 100 years ago, but also the star or individual atoms of it knew already 100 years ago tnat I, who then did not even exist, would view it yesterday evening at such and such a time.”

We believe that we deal here practically with the same paradox. On the one hand, how really a distant star may “know” where and when in the future the emitted photon will be detected? On the other hand, the conception that a photon is a branch only of the exactly consensual interaction between two (may be distant) atoms turns out to be very attractive and finds its beautiful explanation. We believe that some “instantaneity” of such interaction

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[2] One believes incorrectly to tell about “the photon reference frame“ in which this one is immovable.

from “photon’s viewpoint” is fully consistent with the “lab viewpoint” that the photon was emitted in a random direction and after a random finite time met a random absorber. It is a paradox, not a contradiction.

4. Experiments with a photon behavior “delay choice”

In the above situation with a photon the Wheeler’s “delayed choice” idea was claimed – when (in the lab reference frame) the decision about measurement arrangement is made on the final (not initial) stage of the photon propagation or even later. The experiments in **[Ma et al., 2013]** is good example. The layout of the experiment is shown in Fig. 2:

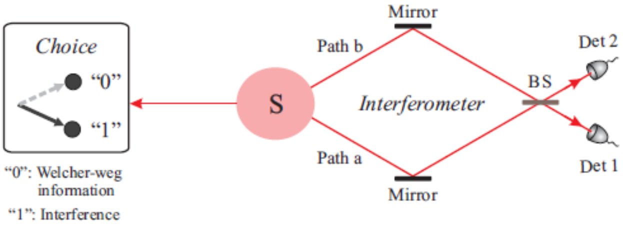

Figure 2. The layout of the experiment from **[Ma et al., 2013]**

In two experimental realizations (Vienna, 2007 and Canary Islands, 2008) the source S emitted path-polarization entangled photon pairs (“system photon” and “system photon”). The system photons propagated through an interferometer, and the environment photons were subject to polarization measurements). Choice acts of measurement type allowing determine which-way information or interference pattern for system photons were made under Einstein locality, i.e. the causality link[3] between the system photon and environment photon was absolutely excluded.

In the experiment the entangled photon pair were created: namely, the entanglement between the system photon path and the environment photon polarization. The system photon was sent into interferometer and the environment photon was sent to the polarization analyzer that performed a measurement under Einstein locality (relative to interferometer events). Due to entanglement between two photons the environment photon polarization determined the which-way information of the system photon.

A quantum random number generator (QRNG) generated a number 0 or 1. If its output was 0, then one performed the polarization measurement of first kind (in the linear basis) on the environment photon and the which-way information for the system photon appeared while the interference could not be observe. Contrary, if QRNG output was 1, then the environment photon was measured in the circular polarization basis and which-way information disappeared (so-called quantum erasure), so the system photon interference appeared.

Thus, the goal of this experiment was the control of a system photon type behavior using a kind of environment photon measurement. The choice-related events and the polarization projection of the environment photon were space-like separated from all events of the interferometric measurement of the system photon. Additionally, the events of choice setting were also space-like separated from the emission of the entangled photon pair from the source. The result turned out to be paradoxical: the system photon detection occurred *earlier* than the measurement on the environment photon, however, behavior of the first one was conditioned by the latest action on the second one; yet, this action was determined before that by the output bit (0 or 1) of the QRNG.

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[3] In the lab reference frame!

5. Two entangled photons

In the case of two “Wheeler’s photons” the situation is more complicate. Let us now consider the above twin paradox in some specially adapted (for two photons) version. Let we have a source S of an entangled photon pair and two perfect fibers with different lengths L1 and L2 > L1, such that their endings (the detectors D) are near one from another. In the lab frame the pair is generated at T0 = 0**.** The first photon will arrive at the first fiber end at T1 = L1/*c*, and the second photon will arrive at the second fibers end at T2 = L2/*c*, where *c* is the speed of light. Hence, these durations difference δt in the lab frame will be

$$\Delta T = (L2 - L1)/c.$$

However, from “the photon viewpoint” *each* duration is instantaneous, so the durations difference is ΔT′ = 0. So, if photons have own clocks and synchronized them at the emission time moment, then the difference between the clock data at the arrivals *was equal to zero*.

As we believe, this paradox can be eliminated by the same way as before (Section 3). All the authors consideration is based on the analysis in the lab reference frame; “from photon viewpoint” the time duration between the measurements on the system photon and environment photon approaches to zero, because of that any inconsistency is impossible. The output bit of QGRN in this time (and from the “photon viewpoint”) is caused by the environment photon action due an exactly the same signal as should be, hence whole triad is correlated.

Note: One could wrongly think that it is possible in a similar experiment to sent a superluminal informational bit if the QGRN was replaced by a discrete signal source in order to have some kind of “telegraph line”. The cause of the rate limitation of such line is that during a bit transport in the line only one EPR-pair should be transported, else a noise will appear instead of an ordered signal sequence. But in the lab frame such minimal existence cycle of only one EPR-pair in the line is exactly equal to the travelling time from source to detector.

It is consistent with the statement from **[Bennett et al., 1993]** that for quantum teleportation a classical subluminal channel is needed additionally to the quantum one.

6. Other experiments with two photons

In the EPR-experiments the entangled photons fly off from an emission source and then are detected by polarizers whose optical axis angle can be changed. There is a correlation between photon pair detection results (yes/no) that depends on the polarizer angle difference Δφ**.** This correlation – in the lab reference frame – seems to be *nonlocal*: from the theoretical viewpoint, in quantum mechanics any possible evolution of Δφ cannot be accounted, the precise and careful experimental investigations confirm that only the value of Δφ just at the measurement time is important.

Indeed, authors of **[Salart et al., 2008]** performed a Bell experiment using entangled photons between two villages in Switzerland separated by 18 km and approximately east-west oriented, with the source located precisely in the middle. The rotation of the Earth allowed them to test all possible hypothetically privileged frames in a period of 24 hours. Two-photon interferences fringes with visibilities well above the threshold set by the Bell inequality were observed at all times of the day. From these observations they conclude that the nonlocal correlations observed here and in previous experiments are indeed truly nonlocal. Indeed, to maintain an explanation based on spooky action at a distance one would have to assume that the spooky action propagates at speeds even greater than the bounds obtained in this experiment.

As I believe, such non-locality disappears “from the photon viewpoint” where the arrival time moments are equal to the start one and hence are *simultaneous*. Just because of that one should determine the polarizer angles synchronously as well as their difference. Therefore, the difference really determines the experiment outcome in all reference frame including the lab one.

It is interestingly also to consider several experiments in which one deals with the delay choice, as it seems, for the electron spin, not for photon. In the paper **[Hensen et al., 2015]** the experiment was described in which the pair of electrons in two labs was separated by 1280 m. However, it turns out that just at the first experiment stage one entangles the distant electron spins (using swapping) with *photons* which are now real actors of experiment, so the proposed explanation is also applicable in this case.

Finally note that in the frame of the proposed picture one can reinterpret the absorber theory of Wheeler and Feynman **[Wheeler, Feynman, 1945]**: it is needless to base a direct particle interaction using some complicate scheme with advanced and retarded waves because from “photon viewpoint” an absorber and emitter interact instantaneously!

7. The hypothesis extension on quantum particles having a mass

We formulated above the hypothesis explaining the non-locality effect in the experiments with photons (EPR, delayed choice, etc.). However, the non-locality is specified also for particles having a mass whose velocity is exactly subluminal, due to this direct extension of the model on the non-locality in the case massive particle should not be make. However, one can try to solve this problem if he accounted that massive quantum particles (particularly, electrons) have also wave-like features, not only particle-like ones.

As it is known **[Dirac,1928]**, the relativistic description of the electron wave function can be given as the system of four differential equations for four spin components, where one pair corresponds to the positive electron energy, and second pair corresponds to the negative one; in each pair one component corresponds to a first spin direction and other component corresponds to the opposite one. At this the operators for the electron velocity components do not commute between themselves and eigenvalues each of them after a measurement should be equal to the speed of light. In 1930 Schrödinger explained such paradoxical result **[Schrödinger, 1930]** by existing of two electron velocity components. One of them is a “usual” one (slow), while another one quickly oscillates with the de Broglie frequency of the electron. The famous British mathematician R. Penrose in his book **[Penrose, 2004]** writes:

> <…> Dirac spinor, <…> with its 4 complex components, can be represented, as a pair of 2-spinors <…> The Dirac equation can then, be written as an equation coupling these two 2-spinors, each acting as a kind of ‘source’ for the other, with a ‘coupling constant’ $M/\sqrt{2}$ [*M* is the mass] describing the strength of the ‘interaction’ between them <…>. From the form of these equations, we see that the Dirac electron can be thought of as being composed of two ingredients <…>. It is possible to obtain a kind of physical interpretation of these ingredients. We form a picture in which there are two ‘particles’, <…> each of which is massless and where each one is continually converting itself into the other one. <…>. Being massless, each of these should be travelling with the speed of light, but we can think of them, rather, as ‘jiggling’ backwards and forwards where the forward motion of the zig is continually being converted to the backward motion of the zag and vice versa. In fact, this is a realization of the phenomenon referred to as ‘zitterbewegung’, according to which, the electron’s instantaneous motion is always measured to be the speed of light, owing to the electron’s jiggling motion, even though the overall averaged motion of the electron is less than light speed. Each ingredient has a spin about its direction of motion, of magnitude $\hbar/2$, where the spin is left-handed in the case of the zig and right-handed for the zag. <…> In this

interpretation, the zig particle acts as the source for the zag particle and the zag particle as a source for the zig particle, the coupling strength being determined by *M.* In the total process, we find that the average rate at which this happens is (reciprocally) related to the mass coupling parameter *M; in* fact, this rate is essentially the *de Broglie frequency* of the electron.

So, while one considers the entangled electrons spins hi necessarily meets a nontrivial wave-like (oscillatory) process where a components interaction (which is not linked with a real electron motion) is specified by the speed of light. But in this case we may believe that above arguments in favor for a relative (not absolute!) non-locality of an experiment with photons can be satisfied for massive quantum particles too**.**

8. Conclusion

In this publication we depart from the simple statement. When some experiment is considered in different reference frames where time currency is sufficiently different, one have to account that the results comparison should have the objective character for the same 4-events. However, in this case several paradoxical situations may appear, and several properties (particularly, non-locality) may turn out become relative ones.

For example, in the twin paradox the ages of the Terrestrial and Astronaut are compared at the same 4-points of spacetime (initial and final). However, their age increments are calculated in the different reference frames exactly as Relativity requires; so, the paradox should be appeared and it really appears!

From my point of view, one can observe the similar situation in a quantum experiment with nonlocal correlations between photons. The results established in different reference frames that can be compared at the same initial and final conditions lead to seamed paradoxes. However, such paradoxes are inevitable ones and correspond to the object properties in different reference frames.

What about entangled pair of quantum particles having a nonzero mass and propagating with a subluminal velocity, we already considered the arguments in favor of this hypothesis in the previous Section. The same arguments should be applicable for the teleportation experiments.

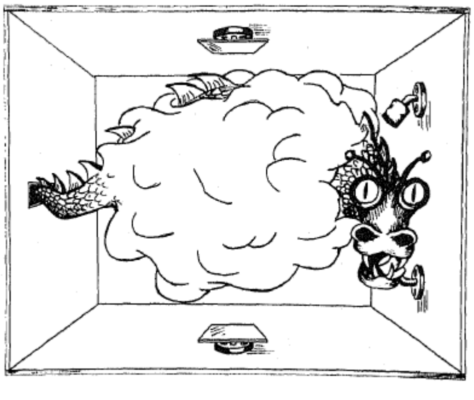

Figure 3. The quantum “phenomenon” can be viewed as a “great smoky dragon”. Figure taken from **[Miller and Wheeler, 1983]** and reproduced In the review **[Ma et al., 2016]**

As it is pointed out in **[Ma et al., 2016]**, “Miller and Wheeler vividly illustrated the concept of “elementary quantum phenomenon” in a cartoon shown in Fig. 3. The sharp tail and head of a dragon correspond to Bohr's “specified circumstances” (the experimental preparation and arrangement) and the result of the observation (the outcome of the experiment), respectively. The body of the dragon, between its head and tail, is unknown and smoky: “But about what the dragon does or looks like in between we have no right to speak, either in this or any delayed-choice experiment. We get a counter reading but we neither know nor have the right to say how it came. The elementary quantum phenomenon is the strangest thing in this strange world." **[Miller and Wheeler, 1983]**.

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