Photon Non-physical Interactions and Quantum Enigmas

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Abstract

A systematic analysis of the simplest quantum optics experiment of linearly polarized photons with a beam-splitter leads to several quantum enigmas, which cannot be explained on the basis of quantum positivism or quantum optics. The fact that photons demonstrate under the "No-Click" conditions non-physical interactions at detector shows that quantum mechanics paradigm is deficient. The study raises philosophical, foundational, and paradigmatic issues with respect to limitations of quantum mechanics.

Keywords

Photon, Beam-Splitter, Non-physical Interactions, Quantum Enigmas, Deficient Paradigm

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1. Introduction

"I thought a hundred times as much about the quantum problems as I have about general relativity theory."

Albert Einstein

"I can safely say nobody understands quantum mechanics."

Richard Feynman

Quantum mechanics (QM) is an outstanding scientific achievement of the 20^{th} century with impact on other branches of science, such as particle physics, chemistry, and cosmology.

In spite of the QM triumph, there are some fundamental reservations on the part of leading quantum scientists. Einstein never accepted QM as a complete theory. On many occasions he stated that QM is compelling as a probabilistic theory, but it is not a complete theory [1].

The leading scientists, such as Murray Gell-Mann [2], Richard Feynman [3], David Bohm [4], John Bell [5] and Roger Penrose [6], had their reservations about QM. These reservations can be summarized as, "nobody understands QM; it explains nothing; it is full of enigmas; it provides only formulae for calculation of the expectation value." QM is a science without ontology. As a probabilistic science, it cannot explain individual quantum systems or individual quantum processes. QM deals successfully with quantum assemblies but not with individual quantum entities, such as photon, electron and other elementary particles. That is the principal reason why "nobody understands QM."

Einstein stated: "…if the statistical quantum theory does not pretend to describe the individual system (and its development in time) completely, it appears unavoidable to look elsewhere for a complete description of the individual system…" [7]

Following Einstein, if we want to uncover fundamental limitations and deficiencies of QM, then we should pursue a detailed and rigorous analysis of experimental performance dealing with individual elementary quantum systems and processes. The most promising field for accomplishing this is quantum optics. In quantum optics one can use a recently developed single photon source, the down-conversion (to be explained later).

Here I propose to use the simplest quantum optics experiment, the beam-splitter with a single photon source. Such experiments have been performed routinely for many years or even decades in many quantum research labs

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including undergraduate labs. I propose to proceed step by step with a rigorous analysis of existing experimental data of such experiments. As demonstrated in this study, such step-by-step analysis shows a glimpse of quantum reality unknown so far. *Unfamiliar new face of QM is emerging.*

The purpose of this study is to show, using the simplest quantum optics experiment, that photon experimental performance cannot be explained based on known and well established quantum physical properties. It is demonstrated in a clear cut way that under certain conditions, photon exhibits *non-physical properties and non-physical interactions.*

2. Photon as a Wave Packet

In quantum optics it is customary to describe photon as a wave packet with all its physical parameters assigned, such as angular frequency ω, wavelength λ, energy $E = \hbar\omega$, dynamic mass $m = E/c^2$, momentum $p = E/c$, and spin S. In quantum optics value of photon spin depends on degree of photon polarization. As experimentally shown, spin can have any value in the range of [-1, +1] in units of Planck constant $\hbar$. At maximum polarization, called linear polarization, spin is equal zero. Such range of photon spin values is unique only to quantum optics, where photon can have circular or linear, or elliptical polarization.

What is the wave packet? Is it a probabilistic mathematical entity or a physical object? The wave packet could not be a physical object since a photon as a massless elementary particle traveling in free space with velocity of light, in accordance with special relativity, has no dimension in the direction of travel.

It is *a QM enigma 1*.

3. Beam-Splitter Experiment with Linearly Polarized Photons

In spite of the fact that the beam-splitter experiment with linearly polarized photons is the simplest experiment in quantum optics [10], [11], [12], surprisingly, it leads to several still unexplained quantum enigmas.

A conceptual high-end experimental layout is shown in Fig.1. As a source of correlated photons it is customary to use the spontaneous parametric down-conversion which produces a stream of individual pairs of secondary photons correlated in energy, momentum and polarization.

The down-conversion is an increasingly popular source of correlated photons. It is widely described in quantum optics literature [8], [9], [10], [11]. Typically, a laser beam, serving as a source of primary photons (P), is directed to a beta-barium-borate (BBO) nonlinear crystal for production of correlated pairs of secondary photons via type-I spontaneous parametric down-conversion.

One should consider the down-conversion process as a splitting of a primary individual photon into a pair of secondary photons.

We assume for the purpose of this study that primary photons are mono-energetic with the precise value of wavelength λ_p selected in a range of 400-500 nm.

A typical layout is designed to produce degenerate pairs leaving the crystal symmetrically at ±3 degrees, where $w_p = w_s + w_g$; $w_s = w_g$; and w_p, w_s, w_g are primary, signal and gating angular frequencies respectively. For convenience, the stream of primary photons is linearly polarized (e.g. in horizontal plane). As a result, the secondary pairs of photons are linearly polarized in vertical plane [12].

Each pair of photons consists of a designated "signal" photon and a designated "gating" photon. After leaving the crystal, photons of each pair travel in separate directions: the gating photon travels to a gating photon detector D_g, and the signal photon is directed at 45 degrees to a polarizing beam-splitter (PBS) with two signal photon detectors D_s1 and D_s2 attached to its output ports. Such angle of 45 degrees is achieved by the rotation of the primary beam polarization plane relative to the PBS horizontal plane.

The advantage of this technique is that when a gating photon is registered by a gating photon detector, we know via coincidence that its partner, a signal photon, is sent to the PBS. Any other so called "extraneous" photons traveling through experimental layout but not confirmed by a gating detector are ignored.

In front of each detector we install a band-pass filter [11]: a filter F_g with a typical bandwidth of 5 nm is placed in front of detector D_g; two identical filters F_s1 and F_s2 with a typical bandwidth of 10 nm are placed in front of the detectors D_s1 and D_s2, accordingly. All filters are tuned on the same central wavelength $\lambda_0 = 2\lambda_p$.

Quantum optics scientists cannot explain the ontology of the linear polarization for an individual photon.

This is *a QM enigma 2*.

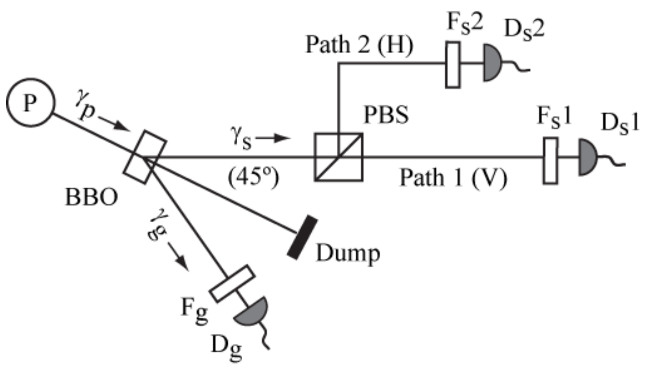

Figure 1. P – laser; γ_p, γ_s, and γ_g – primary, signal and gating photons; PBS – polarizing beam-splitter; BBO – nonlinear crystal; (H) and (V) – horizontal and vertical polarizations; D_s1 and D_s2 – signal detectors; D_g – gating detector; F_s1, F_s2 and F_g – pass-band filters.

According to quantum optics, after passing through the PBS, each signal photon is in the superposition of two quantum states: vertical polarization (V) on path 1 and horizontal polarization (H) on path 2.

How is it possible for a physically indivisible photon to travel along two separate paths? How can one explain the ontology of the superposition?

It is *a QM enigma 3*.

4. Interpretation of the Experiment on the Basis of Quantum Positivism

Quantum positivism, as expressed by Bohr [13], Heisenberg [14], and other members of the Copenhagen Group, denies "any form of physical reality to the dynamic properties (such as position, velocity, momentum, energy) of a quantum system unless they are actually measured." [15] It states that a quantum particle is in intrinsic fuzziness of all potentialities; only when measured or observed it arrives at a definite quantum state.

Here is an example of quantum positivism explanation of our beam- splitter experiment on how a single photon can be in two places, on path 1 and path 2, in the same time. Paraphrasing Brian Green's eloquent and "pure" quantum positivism formulation [16], which we adapted to the beam-splitter experiment: *after emerging from beam splitter, a photon hovers in quantum limbo in a fuzzy, amorphous, probabilistic mixture of two possibilities; only when measured one definite outcome is selected from two possible quantum states: either path 1 with vertical polarization or path 2 with horizontal polarization.*

According to quantum positivism, a photon is not real unless it is observed or measured.

Einstein stated: "I am not a positivist. Positivism states that what cannot be observed does not exist. The conception is scientifically indefensible, for it is impossible to make valid affirmations of what people 'can' or 'cannot' observe. One would have to say that 'only what we observe exists' which is obviously false." [17]

5. Interpretation of the Experiment by Quantum Optics Scientists

First, let us further discuss the layout shown in Fig. 1. Probabilistically, only one half of the photons passes through the PBS as vertically polarized and is registered by detector D_s1, and the other half get reflected as horizontally polarized and is registered by detector D_s2. Each photon is registered by only one of two detectors with equal probability 50/50. *The question quantum optics scientists ask: when does an individual photon decide which path to take, path 1 or path 2?*

Quantum optics physicists believe that photon does not make such decision *inside the PBS*. Each photon emerges from the PBS in the superposition of two equal possibilities: either path 1 with vertical polarization (V) or path 2 with horizontal polarization (H).

Suarez entitles his paper as "Decision at the beam-splitter, or decision at detection, that is a question." His answer is "photon makes decision at detection." [18]

According to Zeilinger, an individual photon decides which path to take only at the moment it is registered by one of two detectors (in our case, D_s1 or D_s2). "A photon actually does *not* decide at the moment when is leaves the beam-splitter what to do."… "The superposition collapses in the moment when the photon is registered by either one of the [D_s1 or D_s2] detectors."… "And only at *that* moment does the photon decide which path it took." [19]

In principle, both detectors can be placed deep in space and separated by several light years. Then instantaneous collapse of the superposition more dramatically illustrates the conflict with special relativity.

Here is *a QM enigma 4*.

As one can see, quantum mechanics leads us into quantum enigma quagmire. Photon physical indivisibility and scientific validity of special relativity would have to be put under a question mark. It would be a high price to pay to maintain the myth that "quantum mechanics has never been proven wrong."

6. Non-physical Interactions with Detector

In the layout shown in Fig.1, let us assume that we remove one signal detector, such as $D_S 1$, and keep in place the other detector $D_S 2$. If the detector $D_S 2$ clicks, then we know that the superposition collapsed and signal photon is registered by $D_S 2$.

However, if after sending a signal photon to the PBS, the detector $D_S 2$ does not "click", then we also know that the photon is traveling along path 1. Somehow, the photon has made its decision without being registered by the only detector we have, namely $D_S 2$. In such case, even without a registration by a detector, we know exactly which path the photon decided to take.

It implies that the "*no click*" is sufficient to collapse the superposition and direct photon along path 1.

That is *a QM enigma 5*.

The collapse of the superposition with the "no click" cannot be explained within the existing paradigm of quantum mechanics. Probabilistic quantum mechanics has difficulties in explaining individual quantum entities or processes. QM deals successfully only with assemblies. As Einstein said, a quantum theory which does not explain reality of individual quantum entities or processes, is not a complete theory.

In fact, the collapse of the superposition caused by the "no click" detector action, is an earth shattering event. But it appears that no one noticed the fact that non-physical action by detector $D_S 2$ causes the collapse of the superposition. No explanation of this fact can be found within the existing QM paradigm.

This is *a QM enigma 6*.

7. Conclusion

In our experiment, photons do not need to be linearly polarized. Photons could have any polarization: circular, elliptical, or linear. It would make no difference – the result and explanation would be the same. The linear polarization provides us with the simplest experimental setup: when photons enter the beam splitter at 45 degrees they have the 50/50 probability to be detected either on path 1 or path 2.

The beam splitter experiment is the simplest experiment in quantum optics. Still, as one can see, the experiment results in a quantum enigma quagmire.

How is it possible for photon, with no physical dimension in the direction of travel, to interfere with itself?

How is it possible for physically indivisible photon to travel along two paths at the same time?

How is it possible for photon in non-physical interaction with a signal detector to cause a collapse of the superposition?

Here is the explanation.

Physical and non-physical interactions of photon with signal detectors show that photon makes a probabilistic (50/50) decision *inside* the beam-splitter which path to travel *physically*.

Photon emerging from the beam-splitter does not hover in quantum limbo, as stated by quantum positivism. It continues its *steady* travel in a state of superposition along one path *physically* and along other path *non-physically*. If that is the case, then the instantaneous collapse of the superposition over any distance does not contradict special relativity.

All this is a strong indication that the QM paradigm is deficient [20]. *Something is missing in our understanding of fundamentals of quantum reality.* As a probabilistic theory, QM, in principle, cannot explain the ontology of individual elementary quantum entities or individual elementary quantum processes. If we understand this, we would be able to proceed in a major way towards the Second Quantum Revolution.

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