**© M.H. Schulman, 2008** (shulman@dol.ru)

**Interference: alone quantum events simulation**

(Supplemented 01.06.2008)

A correspondence is established between photon counters and detectors of active and reactive power in an analogous model of the optical experiment with photon interference as well as in the two slits experiment model. On this base a way to pass from the classical measurement outcomes to the quantum dichotomic measuring statistics is specified.

## Introduction

In **[Shulman, 2007]** I showed the correctness of the following EPR-Bom experiment representation where two photons fly away from a common source to the respective polarizers. *Before the measurement time moment* the both photons *have not* a fixed polarization (e.g., their polarization pointers are rotated sinchronously). Because of accidental reasons one of two photons will be measured first, after that it gets a fixed polarization state. *Then the second photon gets simultaneuosly the same polarization state* (due to the known quantum non-locality phenomena). Since this moment the experiment can be considered (including the quantitative aspect) as Malus test, in which the second (polarized) photon passes (or not) through the corresponding polarizer. The positive resulting outcome probability is equal to the product of the firsrt event probability (½) and conditional probability corresponding with Malus law, hence, it is ½ $\cos^2 \boldsymbol{\theta}$. Therefore, the probability to get *the identical outcomes* (positive or negative) and the *opposite* outcomes are:

$$P_{identcal} = \cos^2 \boldsymbol{\theta}, \qquad P_{opposite} = 1 - \cos^2 \boldsymbol{\theta} = \sin^2 \boldsymbol{\theta}$$

In the paper I proposed also an obvious interpretation of the photon way to “select” the experiment outcome in order to obtain the correspondence between single photon test statistics and classical polarized light beam measurement results.

Along with EPRB-experiments one can observe the quantum non-locality phenomena also in optical experiments with interferometers (see for review **[Belinskii and Klyshko, 1993]**). In these ones photons may follow different optical ways. If a path choice is not traced, then in several cases even single photons passing leads the interference phenomena that obviously demonstrates the nonlocal process features. The interference just appears depending on a photon wave function phase distribution in different places of a nonlocal optical measurement apparatus. The same situation is typical in so-called many-slits-experiments where a particle (e.g., electron) can arrive at a target by different ways: if we do not trace the way choice, then even single particles traveling leads the interference.

## Experiment with interferometer

Let us consider the widely known simplified schema (Fig. 1) of experiment with an interfrence due to a phase angle difference between two arms. A photon comes to the Mach-Zender interferometer containing two 50% beam splitter. The first one (BS1) splits the input beam on two orthgonally polarized components. In the arm 2 a phase shift is provided, after that the second one (BS2) combines and distributes photons between the detectors D1 and D2.

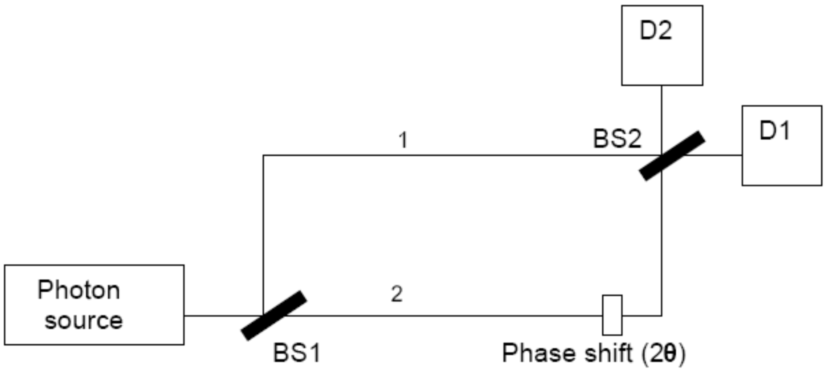


Figure 1. Schema of the experiment with interferometer

Quantum mechanics (QM) predicts photon interference even in the case when photons follow strongly sequentially, one after another. This means that the photon probability to be detected in the detector D1 is not equal to ½ (as if interference is absent), it is equal to

$$P_1 = ½ (1 + \cos 2\boldsymbol{\theta}) = \cos^2 \boldsymbol{\theta}.$$

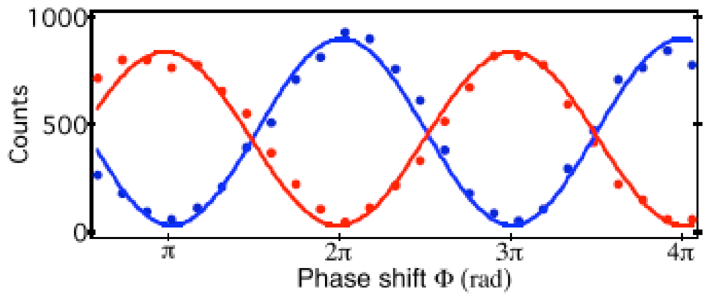


Figure 2 (**[Jacques et al., 2008]**).
Photon counts depending on phase shift **Φ** = 2**θ** between optical ways

On the Fig. 2 the results of the recent experiment **[Jacques et al., 2008]** are shown. They confirm the perfect correspondence with QM predictions.

**Classical analogy**

It is enough instructively to compare the considered quantum situation with a classical analogy. For instance, the experimental schema on Fig. 1 corresponds with the classical schema on Fig. 3, which can be easily analyzed or realized experimentally. In this schema the garmonic signal cos ωt of a sourcr is splitted on two identical components having amplitude ½, then one of them gets a phase shift, i.e. transforms to the signal ½cos(ωt+2**θ**) = ½(cos2**θ** cosωt – sin2**θ** sinωt). After suming we have the output signal:

$$S = ½[ (1+ \cos 2\boldsymbol{\theta}) \cos\omega t – \sin 2\boldsymbol{\theta} \sin\omega t) = \cos\boldsymbol{\theta} (\cos\boldsymbol{\theta} \cos \omega t – \sin\boldsymbol{\theta} \sin\omega t)$$

Note, the output total signal amplitude differs (by factor cos**θ**) from the source signal amplitude. It can be explained as follow: when we increase the pase shift from zero, the full power receiving from an *ideal signal source* changes too and may be even become equal to zero (while two channel phases are opposite). Like that, two opposite mechanical forces in a common spatial point create a balance without energy consuming (ideally).

One can compute the quanttities proportional to the *active* and *reactive* power of the resulting signal using detectors $D_A$ and $D_R$. It is easy to see that the *relative* fractions of the active and reactive power are again $\cos^2 \boldsymbol{\theta}$ и $\sin^2 \boldsymbol{\theta}$. In particular, if the pase shift is $2\boldsymbol{\theta} = \pi/2$, then we come to the both power components identity as it should be.

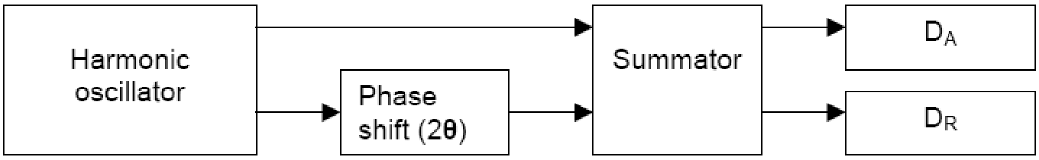


Figure 3. Classical analogy of experiment with interferometer

What is a meaning of the power splitting onto the active and reactive components? In the upper output channel (at the right from the summator) an *irreversible* energy transport into detector $D_A$ is provided over each period of the harmonic signal. Contrary, in the lower channel the mean energy transport into detector $D_R$ over each period is always equal to zero (the power pulses with the doubled frequency). Because of that one has to use the *squared (effective) value* detectors to measure the both components.

**Single photon behavior model**

Now it is clear how we should treat the experiments with single photons where outcomes are strongly dichotomic. The single event (a photon detection by the detectors D1 and D2) statistics has to approach to analogous measurement data of power component detectors $D_A$ (active) and $D_R$ (reactive). It leads that the detection probabilities for D1 and D2 are equal respectively:

$$P_1 = \cos^2 \boldsymbol{\theta}, \quad P_2 = \sin^2 \boldsymbol{\theta}$$

In order to single photon could "decide" what detector it will select it has to "have the information" on a phase shift between two channel, althought it follows one of them only from non quantum pointview. This just confirms the nonlocal situation feature.

What a physical mechanism of a "filter" may be that distributes a single photon to the one detector or to another one? In **[Shulman, 2007]** I proposed a working logic of the polarizer as such filter. Generally, this schema may be actual for any filter.

An arriving photon has to overcome some energetic threshold that height is determined with account of non-locality factor and is equal to $\cos^2 \boldsymbol{\theta}$. Although a poton has constant energy it presents a sum of two oscillating parts – electrical and magnetic. Each photon arriving at the filter has some determined (although accidental) phase, i.e. corresponding accidental instant fraction of electrical field intensity and energy. If this energy fraction overcomes the threshold, then the photon will travel through the filter. So, *photons are sorted between the detectors using relation between the electrical and magnetic energy that they have just at the detection moment.*

Note, if it is true, then quantum indeterminism (at least, in this case) can be explained using a classical *external* fortuity, whereas quantum non-locality holds its fundamental nonlocal origin.

The output harmonic signal component S arriving at a detector may be normalized and set with correspondence to its quantum counterpart – the wave function Ψ; therefore, a power component effective value ($S^*\cdot S$) of this signal may be set with correspondence to a probability ($\Psi^*\cdot\Psi$) of the photon detection by the detector. What about the normalizing factor cos **θ**, one should account that photon stream does not correspond to a signal source with a fixed amplitude, it corresponds to a source with a fixed power. Hence, a photon arriving at one of two detectors is inevitable.

So, the experiment outcome is nonlocal as well in the frame of the classical description as in the quantum frame. The question is only: how quickly in the classical experiment version the output result will change while we change a phase shift between channels.

**On two slits experiment**

The two slits experiment[1] is very close to the interferometric one. An electron from a source travelling through either one or another slit arrives at the target ecran and creates there a mark. If one does not trace the electron trajectory by any measurement, then an interference picture (a serie of maximums and minimums) appears on the ecran. Such picture appears even if electrons leave the source one by one, i.e. enough rarely, so each electron cannot interfere with another one. The marks probability distribution on the ecran is given by the known rule (one should add probability amplitudes, not the probabilities themselves), however, this rule for a *single* particle cannot be deduced only from the *spatial* nonlocality. It even may seem that every single particle mistically *selects* a slit as it knew the *future* distribution.

It is easy to build the analogous classical model for this experiment too, in the frame of which the full (complex) power of the particles flow coming to each ecran point can be separated on *two* components: *active* and *reactive*. The interference is due to the *active* one only, while *the full power is constant for the fixed point*.

Traditionally, one considers a particle flying through a slit as immutable one. However, the analysis for the classical model allows to believe that each single particle experiences an *oscillating* evolution of its state, so *distinct* detection outcomes are possible at the moment of its arriving at the ecran. For example, as has been noted above, the photon electrical or magnetic energy component may dominate at the detection moment. Analogously, other particles may be sorted depending on kinetic and potential energy relation at the detection moment. Hence, *the detection outcome may differ from the full particles amount* (the full flow power) that arrive to the ecran point. This difference is not the same for distinct points of ecran, that just leads to the interference picture.

**References:**

**[Belinskii and Klyshko, 1993]** Belinskii A.V., Klyshko D.N. "The interference of light and the Bell's theorem", Uspekhi Fizicheskikh Nauk, August 1993г, Vol. 163, № 8 – 1 – 45.
**[Feynman et al., 1963]** Feynman R., Leighton R., Sands M. The Feynman lectures on physics. Addison Wesley Publishing Company, inc., 1963.

[1] See, for example, **[Feynman et al., 1963]**

**[Jacques et al., 2008]** Vincent Jacques, E Wu, Frederic Grosshans, Francois Treussart, Philippe Grangier, Alain Aspect and Jean-Francois Roch. "Delayed-choice test of complementarity with single photons" **(**arXiv:0801.0979v1 [quant-ph] 7 Jan 2008)
**Shulman, 2007]** M.H. Shulman. "EPR: alone quantum events simulation". Available at http://timeorigin21.narod.ru/eng_quantum/EPR_events__eng.pdf