CAN ATOM BE CONSIDERED AS A PHOTON TRAJECTORY DETECTOR
(COLLAPSE AS SPONTANEOUS SUPERPOSITION BREAKING)

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Abstract

In this work we theoretically consider a variation of remarkable experiment of the single photon interference at beam splitter. As photon trajectories micro-detector we consider other photon (entangled with the first photon via Hong-Ou-Mandel effect) in common with two identical simple two-level systems (practically two atoms) placed respectively at two beam splitter outcomes. Any two-level system is initially in ground state, but it can absorb one photon when it turns out in excited state. In this way we obtain unambiguously quantum entanglement between one photon and mentioned micro-detector of the photon trajectories, i.e. Schrödinger cat effect. Later sub-systemic detection of the photon by detection photo plate will point out effective absence of the interference patterns, i.e. presence of the statistical mixture of two photon trajectories. All this can be very important for the quantum mechanics foundation since it clearly demonstrates that quantum superposition breaking, i.e. collapse has not absolute character. We discuss a consistent model of the collapse as spontaneous (non-dynamical) breaking (effective hiding) of the unitary symmetry (that conserves superposition) of the quantum dynamics. This model (that includes some type of Landau continuous phase transition) we apply at recent experimental data on the single photon interference at a diaphragm with two slits (V. Jacques, E. Wu, et al.) too.

Key words: entanglement, Hong-Ou-Mandel effect, spontaneous superposition breaking
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1. Introduction

As it is well-known theoretically considered experiment of the interference of single quantum system (photon, electron, etc.) at a diaphragm with two slits or, analogously, at beam splitter [1]-[6] (in excellent agreement with real experimental facts [7]) represents corner stone for demonstration of the basic principles of the standard quantum mechanical formalism [2], [3], [8]-[10]. In this work we shall theoretically consider a variation of remarkable experiment of the single photon interference at beam splitter. As photon trajectories micro-detector we shall consider other photon (entangled with the first photon via Hong-Ou-Mandel effect [11], [12]) in common with two identical simple two-level systems (practically two atoms) placed respectively at two beam splitter outcomes. Any two-level system is initially in ground state, but it can absorb one photon when it turns out in excited state. In this way we obtain unambiguously quantum entanglement between one photon and mentioned micro-detector of the photon trajectories, i.e. Schrödinger cat effect. Later sub-systemic detection of the photon by detection photo plate will point out effective absence of the interference patterns, i.e. presence of the statistical mixture of two photon trajectories. All this can be very important for the quantum mechanics foundation since it clearly demonstrates that quantum superposition breaking, i.e. collapse has not absolute character. We discuss a consistent model of the collapse as spontaneous (non-dynamical) breaking (effective hiding) of the unitary symmetry (that conserves superposition) of the quantum dynamics. This model (that includes some type of Landau continuous phase transition) we shall apply at recent experimental data on the single photon interference at a “diaphragm with two slits” (V. Jacques, E. Wu, et al.) [7] too.

2. Interference of the single photon at beam splitter and basic problem of the quantum mechanics foundation

Usual experiment of the single quantum system, e.g. photon interference at beam splitter (without photon trajectories detection) is presented at Figure 1. Here SL represents source of the single photon P placed left in respect to ideal, symmetric, 1:1 beam splitter BS, MU and MR represent two total mirrors placed up and right in respect to BS and DPP represents fixed (non-movable) detection photo plate than can detect any individual photon as well as statistical distribution of the statistical ensemble of the photons, including interference patterns (many local minimums and maximums of the distribution along DPP axis) when they exist as it is real case when photon trajectory detector D is absent. It is very important that the following be pointed out that it is supposed that all mentioned BS, MU, MR and DPP are fixed (non-movable) in sense that energy-momentum change between mentioned elements and P cannot be realized. So, P emitted by SL propagates in quantum state |PSL> toward BS for input angle π/4. After short quantum dynamical interaction with BS in time moment chosen to be initial, P deterministically turns out in the following quantum superposition of quantum “up” state |↑ (t)> and quantum “right” state |→ (t)> (which holds the same space direction as |PSL>)
corresponding to two BS outcomes

(1) \[ i \, 2^{1/2} | \uparrow (t) \rangle + 2^{1/2} | \rightarrow (t) \rangle = i \, (2^{1/2} | \uparrow (t) \rangle - i \, 2^{1/2} | \rightarrow (t) \rangle ) \]

Here \( U|\text{PSL}\rangle = U|\rightarrow (0)\rangle = i \, 2^{1/2} | \uparrow (0) \rangle + 2^{1/2} | \rightarrow (0) \rangle \) describes unitary quantum dynamical interaction between P (emitted by SL) and BS with corresponding unitary evolution operator \( U \). Also, during time \( t \) quantum states \(| \uparrow (t) \rangle \) and \(| \rightarrow (t) \rangle \) correspond to photon trajectories between BS and DPP via MU and via MR respectively. Mentioned quantum states or quantum trajectories define a complete basis in two-dimensional Hilbert space \( H \) of single photon trajectory states. (As it is well-known two basis states are always mutually linearly independent! Also, as it is well-known, quantum states, including basis states are determined till phase factor of the unit norm. For this reason here, in (1), as well as later, in (3), second term is explicitly presented. It admits better correspondence between formally different presentations of Hong-Ou-Mandel effect.) In this situation DPP finally detects interference patterns corresponding to quantum superposition (1).

![Figure 1.](image1.png) ![Figure 2.](image2.png)

But if in the previous experimental arrangement a photon trajectory detector D is added (as it is formally presented at Figure 2.) DPP will finally detect effective superposition breaking or effective absence of the interference patterns. More accurately DPP will effectively detect statistical mixture of quantum states \(| \uparrow (t) \rangle \) and \(| \rightarrow (t) \rangle \) with corresponding statistical weights \(| i \, 2^{1/2} |^2 = 1/2 \) and \(| 2^{1/2} |^2 = 1/2 \).

As it has been discussed in different gedanken variants of mentioned single photon interference experiments [1], [4], [5] D can be in principle even BS, MU, MR and DPP under condition that they are not fixed, but movable. If, for example, only DPP is movable, energy-momentum change between P and DPP can realize entanglement between motion of P and motion of DPP so that DPP can behave as a pointer of P trajectory which implies breaking of quantum superposition (1) or transition in the
statistical mixture of the photon trajectories (as it is presented at Figure 3.). Here, on the one hand, there is extremely hard technical problem of the realization of the entanglement between P as micro-object and DPP as macro-object. On the other hand, there is principal question what exactly quantum theoretically mean words “fixed” (“non-movable”) and “movable” as well as how changes character of the detection results by “continuous”(or realized by small “discrete” steps) transition from “fixed” into “movable” DPP and vice versa. Feynman [4] shortly observed that even in an intermediate situation, when detection apparatus is neither totally “fixed” nor totally “movable”, standard quantum mechanical formalism and experimental results, do not admit simultaneous appearance of any single photon trajectory and photon trajectories superposition. In such intermediate situation, Feynman suggested, there is a statistical mixture of DPP which behaves as D and DPP which does not behave as D with statistical weights depending of the “degree of the fixation”. More accurately, between sharp
detection of the photon trajectories superposition and sharp detection of the photon trajectories statistical mixture (with superposition breaking ) a “continuous” phase transition, i.e. a series of the un-sharp detections

Both mentioned problems of gedanken experiment at Figure 3. can be solved in realistic experiment presented at Figure 4. Here DPP is again strictly fixed (in usual experimental sense) but its position, at BS-C direction (where C represents cross-point of the reflected and transmitted P) can be discretely changed (by a mechanism analogous to corresponding mechanism in Michelson-interferometer). In this situation character of the detection results depends of the distance d between C and DPP. As it is not hard to see for d=0 experiment at Figure 4. becomes identical to experiment at Figure 1. so that DPP finally detects interference patterns, i.e. quantum superposition. As it is not hard to see too for d equal or larger and larger to one half of photon wave-packet width d(w) two superposition arm or transmitted and reflected photon become more and more weakly interfering and DPP behaves better and better as D that finally effectively detects absence of the interference patterns or statistical mixture of two photon trajectories.

Recently an experiment analogous to mentioned experiment on the single photon
interference at a diaphragm with two slits is realized by V. Jacques, E. Wu, et al. [7]. V. Jacques, E. Wu et al. state: “(ii) we use a wavefront-splitting interferometer based on a Fresnel's biprism, very close to the basic Young's double-slit scheme, (iii) we register the "single-photon clicks" in the interference plane using an intensified CCD camera which provides a real-time movie of the build-up of the single-photon fringes “. [7], pp 1. And “Interferences are created by wavefront-splitting with a Fresnel's biprism and observed by registering the "single-photon clicks" with an intensified CCD camera. This imaging detector provides also a real-time movie of the build-up of the single-photon fringes. We perform a second experiment with two detectors sensitive to photons that follow either one or the other interference path. Evidence for single photon behavior is then obtained from the absence of time coincidence between detections in these two paths. “[7], Abstract. And, finally : “Wavefront-splitting setup based on a Fresnel's biprism (FB). APDs are avalanche silicon photodiodes operating in photon counting regime. An intensified CCD camera (dash line) records interference fringes in the overlapping region of the two deviated wavefronts. When the CCD is removed, it is then possible to demonstrate the single photon behaviour by recording the time coincidences events between the two output channels of the interferometer. “[7], text by Figure 1. Obviously, when instead of elimination of CCD, CCD is discretely translated in right (in respect to Figure 1. in [7]) , step by step , it can realize interference detection in domains where overlapping region becomes smaller and smaller, i.e. weak interference between two superposition terms better and better satisfied. All this means in fact that experiment presented at Figure 4. can be realized by experimental arrangement used in experiment realized by V. Jacques, E. Wu, et al. [7].

Discussed experiment (Figure 4.), [7] implies that effective detection of the quantum superposition breaking need entangled quantum state between two weakly interfering photon trajectories and two weakly interfering domains of (sufficiently large) trajectories detector (here DPP). (Sufficiently large CCD without overlapping region can also detect single photon either in one or in other trajectory.) In opposite case, if mentioned entanglement does not exist, detector (here DPP) can detect quantum superposition. However, in both mentioned experiments, experimental verification of the entanglement and detector (DPP or CCD) is technically extremely hard.

Previously many times used word effective or effectively has an especial meaning. Namely, before (ideal) detection realized by DPP interaction between photon and D must be realized. This interaction, as it is well-known [10] and as it has been previously discussed, must have at least one part that represents quantum dynamical interaction between photon described before interaction by quantum superposition (1) and D described before interaction by corresponding initial quantum state |D (0)> so that, before interaction, quantum super-system P+D (that includes both P and D) is described by non-entangled quantum state (i 2^{-1/2} |↑ (t)> + 2^{-1/2} |→ (t)>) |D (0)> . This state, after mentioned quantum dynamical interaction between P and D (with corresponding von Neumann unitary evolution operator U), deterministically evolves in the following entangled quantum state

\[ 2^{-1/2} |↑ (t)> |D ↑ (t)> + 2^{-1/2} |→ (t)> |D → (t)> \]

where |D ↑ (t)> and |D → (t)> represents eigen states of D pointer observable. (It can
be added that in some non-ideal detections or measurements, quantum dynamical interaction can realize entanglement with numerically changed superposition coefficients. It is very important to be pointed out that for reason of unitarity of quantum dynamical evolution, i.e. von Neumann evolution operator U, pointer observable eigen states cannot be entangled with photon states that represent non-trivial superposition of mentioned trajectories states. Simply speaking, as simple consequence of the unitary quantum dynamics, detector of the photon trajectories cannot detect quantum superposition of trajectories.

Von Neumann [10] supposed ad hoc second part of interaction between P and D that absolutely irreversibly reduces or collapses entangled quantum state (2) in the following statistical mixture of non-entangled quantum states $|\uparrow(t)\rangle|D\uparrow(t)\rangle$ and $|\rightarrow(t)\rangle|D\rightarrow(t)\rangle$ with corresponding statistical weights $|2^{-1/2}|^2 = 1/2$ and $|2^{-1/2}|^2 = 1/2$. This statistical mixture holds simply mentioned statistical mixture of P detected effectively by DPP. So, if von Neumann supposition on the absolute collapse is correct word effectively holds meaning – absolutely. But, as it is well-known, absolute collapse cannot be presented as any unitary symmetric (that conserves quantum superposition) quantum mechanical dynamical evolution in general case on the one hand. On the other hand, in distinction to quantum mechanics, any non-trivial extension of the standard quantum mechanical formalism (e.g. [13]-[15]) that predicts some form of the absolute collapse (mostly as dynamical breaking of the unitary symmetry of the quantum dynamics) must be necessarily super-luminal or non-local [16]-[18]. In this way, as it has been suggested by Bohr [1], [19], concept of the absolute collapse within quantum mechanics is very similar to concept of the absolute space and time within classical mechanics.

It is very important to be observed and pointed out that DPP, if absolute collapse does not exist and if P+D is described by entangled quantum state (2), realizes detection not on the whole quantum super-system P+D, but on the P as quantum sub-system of quantum super-system P+D. Then, according to standard quantum mechanical formalism [8], in respect to such detection by DPP, P is formally described by so-called sub-systemic second kind mixture that formally has identical form as previously mentioned statistical mixture effectively detected by DPP. It means that here word effectively here means relatively (in respect co detection procedure) on the one hand. On the other hand it means that by fixed detection DPP cannot differ is effective collapse absolute or relative. It, as well as fact that entangled quantum state admits in general case many different bi-orthogonal expansions (e.g. EPR systems [20]), does not admit that effective and relative collapse be reduced at the Everett relative states [21]. But it needs a new concept of the collapse. First step in this direction are ideas [22], [23] that collapse in some sense represents an approximate phenomena connected with weak interference (of wave packets) conditions. (However, as it is well-known, at the exact quantum mechanical level of analysis accuracy, superposition of weakly interfering quantum states stands superposition, without any approximate transition in statistical mixture.) Second, very important step in mentioned direction was observation (without detailed physical explanation) [24] that mathematical structure of the standard quantum mechanical formalism admits that collapse be considered as a continuous Landau phase transition. It can be correlated with third step in the same direction, i.e. with old Bohr ideas [1], [19] on approximate “classical” description of the measurement, i.e. detection apparatus in
detection procedure, when an approximate level of analysis accuracy must be introduced. All this admits, as it has been definitely proved [25], [26], that collapse can be considered as the spontaneous (non-dynamical) breaking (effective hiding) of the unitary symmetry (superposition or entanglement) by phase transition from exact quantum in approximate level of the analysis accuracy. It can be considered as an especial case of the general formalism of the spontaneous symmetry breaking that can be successfully applied in many different domains of the physics, e.g. elasticity of rigid bodies, quantum theory of ferromagnetism, and, especially, in quantum theory of electro-weak interactions [27]-[29] as well as in inflation cosmology.

3. Interference of the single photon at beam splitter with micro-detector of the photon trajectories (with Hong-Ou-Mandel effect)

Model of the collapse as spontaneous superposition breaking we shall apply in discussion of the interference of single photon at beam splitter. But more detailed analysis of this question needs firstly a concrete model of the photon trajectories detector D. In usual experiments D is, for practical reasons, a macroscopic system (whose active part can be eventually a mesoscopic system) but for such system corresponding quantum states, including entangled quantum state (2) metaphorically called Schrödinger cat effect, is technically extremely hard for realization. It is not necessary that collision system be a necessary macroscopic or mesoscopic system. Namely, it is well-known [4] that by interference of single electron or photon at diaphragm with two slits D can be a microscopic collision system that can be in principle even single photon (but of course technically is much simpler that experiment be realized with many photons, i.e. macroscopic ensemble of the photons or by a photo camera [7].)

Now we shall theoretically consider a variation of the experiment of single photon interference at beam splitter (without and with photon trajectories detection) where as a realistic photon trajectories micro-detector of the one photon trajectories other photon (entangled with the first via Hong-Ou-Mandel effect [11], [12]) will be used.

At Figure 5. usual experiment of the single photon interference (without photon trajectories detector) is presented. Here, in respect to experiment presented at Figure 1., single photon source SL is eliminated and new single photon source SD down in respect to BS is placed. Simply speaking SD can be obtained by rotation of SL for π/2. Also, it can be supposed that photons emitted by SL and SD are identical, i.e. that both photons have the same wave-length, polarization, etc. So, P emitted by SD propagates in quantum state |PSD> toward BS. After short quantum dynamical interaction with BS in time moment chosen to be initial, P deterministically turns out in the following quantum superposition of quantum “up” state |↑ (t)> (which holds the same space direction as the initial quantum state) and quantum “right” state |→ (t)> corresponding to two BS outcomes

\[
2^{-1/2} |↑ (t)> + i 2^{-1/2} |→ (t)> = i^{1/2} (i2^{-1/2} |↑ (t)> - 2^{-1/2} |→ (t)> )
\]

Here U|PSD> = U|↑(0)> = 2^{-1/2} |↑ (0)> + i2^{-1/2} |→ (0)> describes unitary quantum dynamical interaction between P (emitted by SD) and BS with corresponding unitary
evolution operator $U$. In this situation DPP finally detects interference patterns corresponding to quantum superposition (3).

Consider now experimental arrangement presented at Figure 6. It obviously represents experiment of the single photon interference at beam splitter with both single photon sources SL and SD and without any additional photon trajectories detectors. Suppose additionally that both photons arrive simultaneously at BS which implies typical Hong-Ou-Mandel effect [11], [12]. In this situation both photons simultaneously quantum dynamically interact with BS (as external field), but photons do not quantum dynamically interact mutually. For this reason quantum super-system P+P that includes both photons is described by tensor product of the quantum states (1) and (3), i.e. by non-entangled quantum state

\[
\text{(4)} \quad (i \ 2^{-1/2} |\uparrow(t)\rangle + 2^{-1/2} |\rightarrow(t)\rangle) \ (2^{-1/2} |\uparrow(t)\rangle + i 2^{-1/2} |\rightarrow(t)\rangle)
\]

from Hilbert space $HxH$ with dimension 4 where $x$ denotes tensorial product of the Hilbert spaces $H$ and $H$. This quantum state is equivalent to quantum state

\[
\text{(5)} \quad 2^{-1} (|\uparrow(t)\rangle |\uparrow(t)\rangle + |\rightarrow(t)\rangle |\rightarrow(t)\rangle + i2^{-1} (|\uparrow(t)\rangle |\rightarrow(t)\rangle - |\rightarrow(t)\rangle |\uparrow(t)\rangle)
\]

All four terms in (5) are proportional to four different basis states in corresponding basis in $HxH$. For this reason mentioned basis states or corresponding terms in (5) are linearly independent.

However, since both photons have identical physical characteristics it can be considered that so-called negative interference between two photons or linear dependence between following two basis states

![Figure 5.](image1.png)  
![Figure 6.](image2.png)
must be satisfied. Then (5) turns out in

\[
2^{-1} (|\uparrow (t)\rangle \langle \uparrow (t)| + |\rightarrow (t)\rangle \langle \rightarrow (t)|) = 2^{-1} (-i |\uparrow (t)\rangle \langle i | \uparrow (t)| + |\rightarrow (t)\rangle \langle \rightarrow (t)|)
\]

or, after normalization, in

\[
2^{-1/2} (|\uparrow (t)\rangle \langle \uparrow (t)| + |\rightarrow (t)\rangle \langle \rightarrow (t)|) = 2^{-1/2} (-i |\uparrow (t)\rangle \langle i | \uparrow (t)| + |\rightarrow (t)\rangle \langle \rightarrow (t)|)
\]

Expression (8) represents only formally an entangled quantum state. Namely, reduction of (5) in (8) for reason of identical two photons, implies reduction of Hilbert space of two photons \(HxH\) with dimension 4 in some effective Hilbert space \(H\) with effective dimension 2 corresponding to some effective single photon. Concretely, quantum state \(|\uparrow (t)\rangle \langle \uparrow (t)|\) of two identical photons can be effectively reduced in \(|\uparrow (t)\rangle\) quantum state of effective single photon in homogeneous space statistical micro ensemble of two photons. Simultaneously, quantum state \(|\rightarrow (t)\rangle \langle \rightarrow (t)|\) of two identical photons can be effectively reduced in \(|\rightarrow (t)\rangle\) quantum state of effective single photon in homogeneous space statistical micro ensemble of two photons. Simultaneously, entangled quantum state (8) can be effectively reduced in quantum superposition

\[
2^{-1/2} (|\uparrow (t)\rangle + |\rightarrow (t)|)
\]

It describes effective single photon in homogeneous space statistical micro ensemble of two photons. This quantum superposition (9), i.e. corresponding interference patterns, will be finally detected by DPP.

Thus, for mentioned reasons, von Neumann photon-detector entanglement condition (2) is not really satisfied by (8). In this way experimental arrangement presented at Figure 6. cannot be considered as the detection of the trajectories of single photon emitted by SL using single photon emitted by SR as trajectories detector.

Consider however experimental arrangement presented at Figure 7. Here, in respect to previous experimental arrangement presented at Figure 6, two identical two-level systems, e.g. two atoms, are introduced. Concretely, between BS and MU as well as between BS and MR two-level systems TLSU and TLSR respectively, both initially in ground state \(|G\rangle\), are placed. It will be supposed that difference between energy of excited and ground state of two-level systems is equivalent to photon energy. Also it will be supposed that propagation of two-level systems in respect to photons propagation can be approximately neglected. If two photons propagate along one quantum trajectory then corresponding two-level system quantum dynamically absorbs one photon and turns out in excited state \(|E\rangle\) without any change of the state of other photon. (It will be supposed that life time of two-level system excited state is much larger than time of the propagation of photon between beam splitter and detection photo plate.)

In this way before quantum dynamical interaction between photons and two-level systems quantum super-system \(P+P+TLSU+TLSR\) (that includes both photon and both two-level systems) is described by partially entangled quantum state of
This state after mentioned quantum dynamical interactions deterministically evolves in the following entangled quantum state

\[
2^{1/2} \left( |↑(t)> |G> + |→(t)> |E> \right)
\]

Obviously, there is an excellent correspondence between entangled quantum state (11) and von Neumann entanglement condition (2), where \( |E> |G> \) and \( |G> |E> \) represent eigen states of the pointer observable. It can be observed that corresponding superposition coefficients in (2) and (11) are not identical but absolute values of the corresponding superposition coefficients in (2) and (11) are identical. This fact implies that here detection is not ideal in sense that here effects of dynamical interactions can change in deterministic way values of superposition coefficients in distinction to von Neumann ideal detections where mentioned change does not exist. But this fact has no any principal significance for collapse as superposition breaking or entanglement breaking since (11) as well as (2) represents strictly entangled quantum state.

Finally DPP (that realizes sub-systemic detections at P) will finally detect effective superposition breaking or effective absence of the interference patterns. More accurately DPP will effectively detect statistical mixture of quantum states or trajectories \( |↑(t)> \) and \( |→(t)> \) with corresponding statistical weights \( |2^{1/2}|^2 = 1/2 \) and \( |2^{-1/2}|^2 = 1/2 \) as it is case by usual detection of the photon trajectories by interference of single photon at beam splitter.

All this admits that single photon emitted by SD and two-level systems (two atoms) TLSU and TLSR represent a micro-detector that detects trajectories of single photon emitted by SL. This is practically unambiguous experimental fact on the one hand. On the other hand it is practically unambiguous experimental fact (for existence of
the Hong-Ou-Mandel effect) that there is quantum entanglement between detected photon and mentioned micro-detector (Schrödinger cat effect). It opens a new question, how and where quantum superposition breaking or effective but not absolute transition from quantum superposition in corresponding statistical mixture of quantum states occurs.

4. Basic concepts of the general formalism of the spontaneous (non-dynamical) symmetry breaking (effective hiding)

Now we shall prove that all previously discussed experimental facts can be consistently explained within standard quantum mechanical formalism by model of the collapse as spontaneous (non-dynamical) breaking (effective hiding) of unitary symmetry (that conserves quantum superposition or entanglement) of quantum dynamics. But firstly we must present basic concepts of the general formalism of the spontaneous (non-dynamical) breaking (effective hiding) of some dynamical symmetry.

As it is well-known [27]-[29] there are two principally different ways for breaking of the dynamical symmetry, dynamical and spontaneous (non-dynamical), which will be shortly considered. Basic characteristic of a physical theory that can be applied for description of a physical system is corresponding dynamics. This dynamics or precisely dynamical equations hold corresponding dynamical symmetries. Unique solution of mentioned dynamical equations, if it exists, represents dynamically stable and observable dynamical state that deterministically evolves during time. (Words stable and observable here refer to corresponding dynamics.) Consider situation in which the physical system can be described by two discretely different physical theories, one, more accurate or simply speaking exact, and other, less accurate or simply speaking approximate. (In this sense we can speak about two different levels of analysis accuracy, one exact corresponding to exact theory and other approximate corresponding to approximate theory.) Exact theory can be considered as a non-trivial extension of the approximate theory, while approximate theory can be considered as a non-trivial reduction of the exact theory. There is such situation in which some approximate dynamical symmetry does not represent any exact dynamical symmetry. It means that mentioned approximate dynamical symmetry is not conserved at exact level of analysis accuracy or that mentioned approximate dynamical symmetry becomes broken by transition from approximate at exact level of analysis accuracy, i.e. by means of such exact dynamical terms that do not appear at approximate level of analysis accuracy. It represents dynamical breaking of the approximate dynamical symmetry.

Dynamical symmetry breaking holds many very important applications within physics, classical and quantum. For example, experimentally verified parity breaking in weak interactions is a typical dynamical symmetry breaking. But there are such very important physical situations where concept of the dynamical symmetry breaking cannot be applied at all. For example in attempt of unification of the electromagnetic and weak interaction additional mass term cannot be immediately introduced in the dynamics. Namely such term dynamically breaks gauge symmetry of the electro-weak dynamics without which theory does not admit renormalization and diverges. Also, as it has been previously discussed, absolute collapse or dynamical breaking of unitary symmetric (that conserves quantum superposition or entanglement) quantum dynamics cannot be realized at all by additional (at quantum level of accuracy hidden) dynamical variables from some more accurate level of analysis. Namely, in distinction to relativistic local quantum dynamics, any non-trivial
extension of quantum dynamics that satisfies existing experimental facts must be necessarily relativistic non-local or super-luminal.

There is such situation in which exact dynamics should be approximately reduced or projected in approximate dynamics. For reason of the discrete difference between exact dynamics and approximate dynamics there are different possibilities for realization of mentioned projection. Some exact dynamical state can be globally (i.e. in whole space of the arguments) consistently (convergently) approximated by corresponding approximate dynamical state and then some exact dynamical symmetries become effectively hidden but not broken. Here, roughly speaking, exact dynamical state becomes globally dynamically stable and observable even at the approximate level of analysis accuracy. Some other exact dynamical state that cannot be globally (i.e. in whole space of the arguments) approximated by any corresponding approximate dynamical state. For this reason, exactly existing, exactly dynamically stable and observable dynamical state is globally approximately dynamically non-stable and non-observable. Here, roughly speaking, exact dynamical state becomes globally non-stable and non-observable at the approximate level of analysis accuracy. Finally, there is such exact dynamical state that cannot be globally (i.e. in whole space of the arguments) but can be locally (in some disjunctive domains of the arguments) consistently (convergently) approximated by corresponding local approximate dynamical states. In this sense such exact dynamical state is locally approximately dynamically stable and observable. It means that within any mentioned local domain of arguments approximate dynamics holds one consistent solution, i.e. approximate dynamical state which within this domain can locally represent exact dynamical state. Formally we can speak about spontaneous (non-dynamical) transition from the globally approximately dynamically non-stable exact dynamical state in the locally approximately dynamically stable exact dynamical state. But this transition or this event is inherently probabilistic or statistical. Namely it cannot be described deterministically neither by exact dynamics (within which such transition does not exists at all), nor by approximate dynamics (since its validity is limited in restricted domain of the exact dynamical state arguments). According to usual geometric definition of probability, probability of mentioned transition or event can be defined as the relative measure of corresponding arguments domain. It can be added that here exact dynamical state cannot be simultaneously separated in all local domains in case when its norm must be conserved as it is case within quantum field theory. Finally, after mentioned probabilistic local transition or projection, further deterministic approximate dynamical evolution appears which does not admit reverse transition. Discussed transition by which many, symmetric, local approximate dynamical solutions are probabilistically and irreversible changed by one actual local approximate dynamical solution represents in fact spontaneous symmetry breaking. More accurately speaking we have here effective hiding of the symmetry at approximate level of analysis accuracy (at exact level of analysis accuracy symmetry is not broken but it is conserved).

Spontaneous symmetry breaking holds many very important applications within physics, classical and quantum. Within electro-weak theory exact quantum dynamical solution of the exact dynamical equation exists, but it cannot be obtained analytically. For this reason approximate dynamics, i.e. perturbation theory must be used. Perturbation theory diverges for zero field value (false vacuum), but locally converges for “circularly” distributed field values (real vacuums). Translation, i.e. transition from zero field value (false vacuum) to some field value at “circle” (real vacuum) realizes spontaneous breaking of the “circular symmetry” (in fact gauge symmetry). As it has been detailed discussed in [28], word “translation” here is not conclusive, as well as word “choice” or question “how Nature chose one of equally probable real vacuums”. All mentioned phrases refer on the dynamical
breaking of the symmetry concept. Within spontaneous symmetry breaking there is no “choice” but only irreducibly probabilistic event at approximate, perturbation theory level of accuracy, and exactly conserved gauge symmetry. In domains of not so high energies theory of perturbation can be used as technically simple theoretical method, but it cannot be considered as any principal “choice”.

5. Collapse as spontaneous (non-dynamical) superposition breaking (effective hiding)

As it is well-known within standard quantum mechanical formalism, basic quantum space is Hilbert space of the quantum states with unit norm. Quantum system is completely described by quantum state of the unit norm from Hilbert space and this state strictly deterministically evolves during time according to unitary symmetric quantum (mechanical) dynamics. Physical characteristics of the quantum system are presented by Hermitian operators with real eigen values and referential frames in Hilbert space represent bases of all observables. Quantum dynamical state is presented in some referential frame by quantum superposition over all basic states that define this referential frame. For this reason unitary symmetry of the quantum dynamics (that conserves superposition) simply implies that all referential frames in Hilbert space have the same right and that within Hilbert space there is no absolute referential frame or absolute observer.

It can be observed that only previous few statements express practically all basic concepts of the quantum mechanics as an exact physical theory. (Of course here we do not speak on the necessity of the relativistic generalization of the quantum mechanics toward quantum field theory etc.) Within such exact theory quantum superposition or quantum entanglement as an especial quantum superposition in the Hilbert space of quantum super-system have clear physical sense. It is in excellent agreement with experimental facts that point out that quantum entanglement is not only distance independent[17], [18], but also number of quantum sub-systems and temperature independent [30]. (Within hidden variables and similar physical theories, where it is supposed that usual or phase space represents basic physical space quantum superposition and entanglement cannot obtain clear physical sense without non-plausible super-luminal interactions.) Further we shall shortly consider how exact quantum mechanics can be reduced globally and locally in the approximate classical mechanics that is detailedly discussed in [25], [26].

Suppose that quantum dynamical state represents a wave packet. Under additional, well-known [2],[8],[31] approximation conditions mentioned wave packet can be globally approximately treated as the classical mechanical particle that satisfy approximate classical mechanical dynamical equation. (Namely, in Ehrenfest picture, average value of the quantum dynamical equation can be Taylor expanded [31] so that first term in expansion represents classical dynamical term for average coordinate value while other terms are proportional to increasing degrees of the coordinate uncertainty exponents. If coordinate average value is much larger than coordinate uncertainty, i.e. wave packet width, first term turns out in classical dynamical term for wave packet while other terms can be effectively neglected. Down limit of such wave packet approximation is characterized by Heisenberg uncertainty relations.) In this way (until all approximation conditions are satisfied) classical mechanics can be considered as approximate physical theory.

Consider exactly quantum mechanically two wave packets with practically the same (coordinate intervals) widths. It can be considered that mentioned two wave packets weakly interfere if distance between their centers is larger than one width.
Consider quantum dynamical state that represents (non-trivial) superposition of two weakly interfering wave packets. As it has been proved in [25],[26], such quantum superposition cannot be globally classical presented as the classical particle. (Namely, then mentioned Taylor expansion of Ehrenfest average value of the quantum dynamical equation becomes divergent.) Simply speaking, exactly existing superposition of two weakly interfering wave packets, approximately classically is globally non-stable and non-observable. But, of course, mentioned superposition is approximately classically locally stable and observable within any of two wave packets. Then, according to general formalism of the spontaneous symmetry breaking, here inherently probabilistically (with typical quantum mechanical probabilities) and spontaneously event of appearance of one or other wave packet becomes realized at classical level of analysis accuracy. However, at the quantum level of analysis accuracy superposition of weakly interfering wave packets stands conserved. For this reason, as it has been previously discussed, mentioned event appearance does not correspond to any real “choice” if this word “choice” should imply deterministic description of the event within dynamical superposition breaking. However, if by new detection only such quantum observables for which mentioned wave packets represent eigen states will be analyzed, classical level can be used as technically simple theoretical method, but it cannot be considered as any principal “choice”. Then, according to determinism of the classical dynamics, new detector will detect the same wave packet which appears by the previous spontaneous superposition breaking. But if by new detection other (complementary) observables will be detected quantum superposition of weakly interfering wave packets must be used. Obviously all this represents an excellent model of the self-collapse at classical level of analysis accuracy.

Further, consider quantum dynamical state that represents (non-trivial) superposition of two wave packets. Suppose that initially mentioned wave packets are strongly interfering but that, according to deterministic quantum dynamical evolution, distance between centers of wave packets increases during time. Then in moment when wave packets centers become sufficiently distant, i.e. when wave packets become weakly interfering, conditions for self-collapse as spontaneous superposition breaking become satisfied and in this sense we can speak about collapse as a continuous phase transition.

Consider now measurement or detection procedure. Before quantum dynamical interaction between quantum system and detector, quantum system is described by superposition of the eigen states of measured observable, while detector is described by “zero” eigen state of the pointer observable. During deterministic quantum dynamical interaction between quantum system and detector entangled quantum state (bi-orthogonally expanded over quantum system measured observable eigen states and detector pointer observable eigen states) of the quantum super-system (that includes quantum system and detector) becomes realized. This entangled state (in absence of new interactions with additional physical systems) stands conserved during time. Suppose that within mentioned entangled state of super-system detector pointer observable eigen states represent wave packets. Suppose that mentioned wave packets are initially strongly interfering and that mentioned wave packets become during time weakly interfering. In moment when all mentioned wave packets become mutually weakly interfering at the classically described detector self-collapse as spontaneous (non-dynamical) entanglement breaking (effective hiding) appears. In other word, here spontaneous superposition breaking at super-system appears in full analogy with spontaneous superposition breaking at simple system. Simultaneously, for reason of correlations between detector pointer observable eigen states and quantum system measured observable eigen states, in respect to self-collapsed detector quantum system becomes effectively uniquely described by corresponding statistical mixture
of the eigen states of measured observable. It this sense at quantum system relative collapse effectively appears as seemingly “absolute”. But within exact entangled state of super-system statistical mixture by relative collapse of the quantum system is one of many possible second kind mixtures of this quantum system. Relative collapse at quantum system is effective but not absolute quantum phenomena and it occurs only in respect to classically self-collapsed detector. Super-system that includes quantum system and detector is exactly described by entangled state. If by a new sub-systemic detection at quantum system only, only such quantum observables compatible with previously detected observable will be analyzed, quantum system can be effectively exactly described by statistical mixture characteristic for previous relative collapse. In this sense detections of the first and new detector are identical. But if by new detection other (complementary) observables will be detected entangled state of super-system, i.e. a different second kind mixture of the quantum system must be used. Obviously all this represents an excellent model of the measurement or detection in full agreement with all known experimental data.

6. Collapse as spontaneous superposition breaking and interference of the single photon at beam splitter

Finally we shall consider model of the collapse as spontaneous superposition breaking in previously discussed experiments.

As it is not hard to see, all conditions for the collapse as the spontaneous superposition breaking are satisfied in experiment presented at Figure 4. or in experiment realized by V. Jacques, E. Wu, et al. [7].

But application of the model of the collapse as spontaneous superposition breaking in experiment of the interference of single photon at beam splitter with micro-detector of the photon trajectories (with Hong-Ou-Mandel effect) needs additional discussion. It, in fact, can be reduced on the question are two terms in entangled quantum state (11) really weakly interfering. Answer is not so simple.

First of all it can be observed that non-entangled quantum state (10) describes four quantum systems (two photons and two two-level systems) while entangled quantum state (11) three quantum systems (one photon and two two-level systems). It implies that here an additional simplification (characteristic for standard quantum mechanical formalism [8]), that can be called “paradox” of excited quantum states, is used. (Of course, we shall here consider only simple two-level systems with one ground and one excited state.) Namely, it is well-known that only ground state |G> is quantum dynamically stable while excited state |E> is quantum dynamically non-stable and it quantum dynamically evolve in very complex way during time. Formally speaking excited state |E(t)> evolves in a superposition of initial, non-decayed excited state |E(0)> and final decayed state |P(t)> |G > with corresponding time dependent superposition coefficients. Here |P(t)> represents wave packet of the spontaneously emitted photon that propagates far away in respect to two-level system. For mentioned two-level system and excited quantum state an appropriate time constant, life time, can be defined so that for time moment much smaller that life time excited state can be approximated by |E(0)> while for time moment larger than life time excited state can be approximated by |P(t)> |G >. Strictly speaking, both |E(0)> and |P(t)> |G > must belong to the same Hilbert space which admits that in a rough approximation the following be satisfied
Here $|P(t), \text{TLS}>$ represents some “standing wave packet” or quantum state of the electromagnetic field with average energy equal to energy of one photon, but under additional supposition that mentioned electromagnetic field is localized in some small vicinity of two-level system TLS. Approximation (12) is very rough and even nonsatisfactory for description of the quantum dynamical evolution of the excited state on the one hand. But, on the other hand, it is satisfactory for description of the space localization of the electromagnetic field with errors proportional to linear dimensions of TSL (we can remember that linear dimension of atoms are much smaller that wave lengths of optical photons).

All this admits that approximation (12) be satisfactorily introduced in (11) which implies

\[
2^{1/2} |↑(t)> |P(t), \text{TLSU}> |G> |G> + 2^{-1/2} |→(t)> |P(t), \text{TLSR}> |G> |G> = (2^{1/2} |↑(t)> |P(t), \text{TLSU}> + 2^{-1/2} |→(t)> |P(t), \text{TLSR}> ) |G> |G>.
\]

It, finally, yields entangled quantum state of free photon and localized electromagnetic field

\[
(2^{-1/2} |↑(t)> |P(t), \text{TLSU}> + 2^{1/2} |→(t)> |P(t), \text{TLSR}> )
\]

where, according to previously introduced suppositions, $|P(t), \text{TLSU}>$ that correspond to photon absorbed by TLSU and $|P(t), \text{TLSR}>$ that correspond to photon absorbed by TLSR extremely weakly interfere before detection of free photon by DPP.

In this way conditions of weak interference become satisfied immediately after absorption of one photon by some of two two-level systems and simultaneously self-collapse at two-level systems and relative collapse at free photon effectively appear completely corresponding with later detection of DPP.

### 7. Conclusion

In conclusion the following can be repeated and pointed out. In this work we theoretically consider a variation of remarkable experiment of the single photon interference at beam splitter. As photon trajectories micro-detector we consider other photon (entangled with the first photon via Hong-Ou-Mandel effect) in common with two identical simple two-level systems (practically two atoms) placed respectively at two beam splitter outcomes. Any two-level system is initially in ground state, but it can absorb one photon when it turns out in excited state. In this way we obtain unambiguously quantum entanglement between one photon and mentioned micro-detector of the photon trajectories, i.e. Schrödinger cat effect. Later sub-systemic detection of the photon by detection photo plate will point out effective absence of the interference patterns, i.e. presence of the statistical mixture of two photon trajectories. All this can be very important for the quantum mechanics foundation since it clearly demonstrates that quantum superposition breaking, i.e. collapse has not absolute
character. We discuss a consistent model of the collapse as spontaneous (non-dynamical) breaking (effective hiding) of the unitary symmetry (that conserves superposition) of the quantum dynamics. This model (that includes some type of Landau continuous phase transition) we apply at recent experimental data on the single photon interference at a diaphragm with two slits (V. Jacques, E. Wu, et al.) too.

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