CAN PHOTON BE CONSIDERED AS ITS TRAJECTORY SELF-DETECTOR (SELF-COLLAPSE AS SPONTANEOUS SUPERPOSITION BREAKING)

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Abstract

In this work we theoretically considered variations of remarkable experiments of single photon interference (at beam splitter, at diaphragm with two slits, etc., especially recent experiment of such kind realized by V. Jacques, E. Wu, et al.) or (Hong-Ou-Mandel) two photons interference. In mentioned variations intensity of interference or degree of overlap of photon wave packets in superposition can be changed practically continuously (it can “continuously” increase or decrease). It will be correlated with possibility (shortly noted by Feynman) of a practically “continuous” phase transition from detection of the quantum system trajectories superposition (interference) in detection of the quantum system trajectories statistical mixture (and vice versa) in real experiments. All this can be very important for the quantum mechanics foundation since it clearly demonstrates that quantum superposition breaking, i.e. (self)collapse has not necessarily absolute character as well as that it can be realized at micro-systems (photon, electron, atom, etc.). 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. 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. in elasticity of rigid bodies, quantum theory of ferromagnetism, quantum theory of electro-weak interactions as well as in chaotic inflation cosmology.

Key words: spontaneous superposition breaking, photon
PACS number: 03.65.Ta
1. Introduction

As it is well-known theoretically considered remarkable experiment of the interference of single quantum system (photon, electron, atom, etc.) at a diaphragm with two slits or, analogously, at beam splitter, etc. [1]-[6] (in excellent agreement with real experimental facts [7]) represents corner stone for demonstration of the basic principles of standard quantum mechanical formalism [2], [3], [8]-[10].

In this work we shall theoretically considered variations of remarkable experiments of single photon interference (at beam splitter, at diaphragm with two slits, etc., especially recent experiment of such kind realized by V. Jacques, E. Wu, et al. [7]) or (Hong-Ou-Mandel) two photons interference. In mentioned variations intensity of interference or degree of overlap of photon wave packets in superposition can be changed practically continuously (it can “continuously” increase or decrease). It will be correlated with possibility (shortly noted by Feynman [4]) of a practically “continuous” phase transition from detection of the quantum system trajectories superposition (interference) in detection of the quantum system trajectories statistical mixture (and vice versa) in real experiments. All this can be very important for the quantum mechanics foundation since it clearly demonstrates that quantum superposition breaking, i.e. (self-)collapse has not necessarily absolute character as well as that it can be realized at micro-systems (photon, electron, atom, etc.). 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 [11], [12]. 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. in elasticity of rigid bodies, quantum theory of ferromagnetism, quantum theory of electro-weak interactions as well as in chaotic inflation cosmology [13]-[16].

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 for input angle π/4. Also, MU and MR represent two total mirrors placed up and right in respect to BS and DPP represents detection photo plate. Here MU redirects practically only P reflected by BS toward DPP, while MR redirects practically only P transmitted by BSW toward DPP. Finally, DPP 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. 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 |\text{PSL}\rangle 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 $|\uparrow(t)\rangle$ and quantum “right” state $|\rightarrow(t)\rangle$ (which holds the same space direction as $|\text{PSL}\rangle$) corresponding to two BS outcomes

\begin{equation}
|P(t)\rangle = i 2^{-1/2} |\uparrow(t)\rangle + 2^{-1/2} |\rightarrow(t)\rangle
\end{equation}

Here $U|\text{PSL}\rangle = U|\rightarrow(0)\rangle = i 2^{-1/2} |\uparrow(0)\rangle + 2^{-1/2} |\rightarrow(0)\rangle$ describes deterministic unitary quantum dynamical interaction between P 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. In this situation DPP finally detects interference patterns corresponding to quantum superposition (1).

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

But if in 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 collapse, i.e. 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 (thought) 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

![Figure 3.](image)

![Figure 4.](image)

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.

Last mentioned problem 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 changed (e.g. 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 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. In this way, by mentioned “continuous” increase of d a practically “continuous” phase transition from detection of the quantum system trajectories superposition (interference) in detection of the quantum system trajectories statistical mixture is realized in real experiments.
It can be added that analogous results follow by translation of DPP in opposite direction (toward BS) as it is presented at Figure 5. It includes situation presented at Figure 6. (well-known in usual experiments) where total mirrors MU and MR are changed by two distant parts of detection photo plate DPPU and DPPR respectively. Obviously here mentioned parts of the detection photo plate can be considered as photon trajectories detectors that effectively detect statistical mixture of the photon trajectories.

Consider now more accurately quantum dynamical interaction between P and DPP for \( d=0 \) and \( d=d(w) \).

For reason of formal simplicity suppose that DPP can be considered as one dimensional physical system with space coordinate \( q \).

Define the following three \( q \) space domains at DPP, \( SD(-1) = (-d(w),0) \), \( SD(0) = (-d(w)/2, d(w)/2) \), \( SD(+1) = (0, d(w)) \).

For \( d = 0 \) , immediately before quantum dynamical interaction between P (with practically space coordinate \( q \) from \( SD(0) \)) and DPP, quantum super-system \( P+DPP \) (that includes both P and DPP) is described by the following non-entangled quantum state

\[
|P(t), SD(0)> |DPP, 0> 
\]

Here \( |P(t), SD(0)> \) represents quantum state of P \( (1) \) different from zero only within \( SD(0) \), while \( |DPP, 0> \) represents quantum state of DPP without absorbed P. Immediately after quantum dynamical interaction between P and DPP \( (2) \) turns out in non-entangled quantum state

\[
|P,0, SD(0)> |DPP, 1, SD(0)> 
\]

Here \( |DPP, 1, SD(0)> \) represents quantum state of DPP with one absorbed P in \( SD(0) \) while \( |P,0, SD(0)> \) represents quantum vacuum state without P after absorption of P in \( SD(0) \).

For \( d = d(w) \) , immediately before quantum dynamical interaction between P (with practically space coordinate \( q \) from \( SD(-1,+1) = (-d(w), +d(w)) \)) and DPP, quantum super-system \( P+DPP \) (that includes both P and DPP) is described by the following non-
entangled quantum state

(4) \[ |P(t), SD(-1,+1) > |DPP, 0> \]

Here \(|P(t), SD(-1,+1) >\) represents quantum state of P (1) different from zero only within SD(-1,+1), while \(|DPP, 0>\) represents quantum state of DPP without absorbed P. Immediately after quantum dynamical interaction between P and DPP (2) turns out in entangled quantum state

(5) \[
i^{2-1/2} |\uparrow,0, SD(+1)> |DPP, 1,\uparrow, SD(+1)> +
\]
\[
2^{1/2} |\rightarrow,0, SD(-1)> |DPP, 1,\rightarrow, SD(-1)>.
\]

Here \(|DPP, 1,\uparrow, SD(+1)>\) represents quantum state of DPP with one absorbed reflected P in SD(+1) while \(|\uparrow,0, SD(+1)>\) represents quantum vacuum state without reflected P after absorption of reflected P in SD(+1). Also, here \(|DPP, 1,\rightarrow, SD(-1)>\) represents quantum state of DPP with one absorbed transmitted P in SD(-1) while \(|\rightarrow,0, SD(-1)>\) represents quantum vacuum state without transmitted P after absorption of transmitted P in SD(-1).

As it is not hard to see the same unitary quantum dynamical evolution operator \(U(P+DPP)\) that describes quantum dynamical interaction between P and DPP realizes deterministic evolution of quantum state (2) in (3) (that, formally speaking, conserves superposition at P as sub-system of P+DPP) or quantum state (4) in (5) (that, formally speaking, extends sub-systemic superposition in super-systemic superposition or entanglement at P+DPP).

However, entangled quantum state or especial super-systemic superposition (5) is principally different from super-systemic statistical mixture of the quantum states \(|\rightarrow,0, SD(-1)>\) \(|DPP, 1,\rightarrow, SD(-1)>\) and \(|\uparrow,0, SD(+1)>\) \(|DPP, 1,\uparrow, SD(+1)>\) with corresponding statistical weights \(|i^{2-1/2}|^2 =1/2\) and \(|2^{1/2}|^2 =1/2\). Of course, mentioned super-systemic statistical mixture effectively corresponds to photon trajectories detection.

For this reason von Neumann \([10]\) supposed ad hoc additional part of interaction between P and DPP that absolutely irreversible reduces or collapses entangled quantum state (5) in mentioned super-systemic statistical mixture. But, as it is well-known, such 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. \([16]- [19]\)) 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 \([20]- [22]\). In this way, as it has been suggested by Bohr \([1], [23]\), concept of the absolute collapse within quantum mechanics is very similar to concept of the absolute space and time within classical mechanics.

It is well-known too that entangled quantum state admits in general case many different bi-orthogonal expansions (e.g. EPR systems \([24]\)). For this reason effective and relative collapse cannot be reduced at the Everett relative states \([25]\) but it needs a new concept. First step in this direction are ideas \([26], [27]\) 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) [28] 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], [23] 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 [11], [12], 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. in elasticity of rigid bodies, quantum theory of ferromagnetism, quantum theory of electro-weak interactions as well as in chaotic inflation cosmology [13]-[16].

3. 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 [13]-[15] 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 (convergent) 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 (convergent) 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”.

4. 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 Hermitean 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 an excellent agreement with experimental facts that point out that quantum entanglement is not only distance independent[21], [22], but also number of quantum sub-systems and temperature independent [29]. (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 mechanic that is detailed discussed in [11], [12].

Suppose that quantum dynamical state represents a wave packet. Under additional, well-known [2],[8],[30] 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 [30] 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 [11],[12], 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.

Additionally, consider shortly, such inverted experimental situation where quantum dynamical state represents (non-trivial) superposition of two wave packets. Suppose that initially mentioned wave packets are weakly interfering but that, according to deterministic quantum dynamical evolution, distance between centers of wave packets decreases during time. Then in moment when distance between wave packets centers becomes equal or smaller than one wave packet width, i.e. when wave packets become non-weakly interfering, conditions for self-collapse as spontaneous superposition breaking become non-satisfied and in this sense we can speak about disappearance of the collapse (at approximate level of analysis accuracy) and “restored” superposition of two wave packets (at exact level of analysis accuracy) as a (inverse) continuous phase transition.

As the first example of mentioned inverse phase transition we can consider analogous phase transition from two non-entangled photons in two entangled photons is realized in experimentally verified Hong-Ou-Mandel effect of the (negative) interference (superposition) of two photons (with all identical physical characteristics) at beam splitter [31], [32]. Namely, as it is well-known, when two photons (with all identical physical characteristics) that arrive at two different inputs of beam splitter overlap totally in time as the result of the totally realized negative interference there is absolute absence of coincident photons (which simultaneously propagate in two different output of beam splitter). In this situation two photons that leave beam splitter propagate in entangled state, i.e. superposition of two photons that both propagate in one and two photons that both propagates in other beam splitter output. But when two photons (with all identical physical characteristics) that arrive at two different inputs of beam splitter do not overlap totally in time amplitude of the detected coincident photons increases and becomes larger and larger when input photons overlap becomes smaller and smaller. (Of
course, when overlap in time of two input photons (with all identical physical characteristics) disappears, i.e. when two mentioned photons weakly interfere in time, we have situation in which two photons, one after other, interact independently with beam splitter.)

As the second example of mentioned inverse phase transition we can consider following experimental situation. Here in which two photons (with identical all physical characteristics) propagate from two directions, “left” and “down”, toward single simple two-level system (an atom for example) that is initially in the ground state \(|G\rangle\). It will be supposed that motion of the two-level system during photons propagation as well as during quantum dynamical interaction with the photons can be effectively neglected.

Suppose also that life time of the excited state \(|E\rangle\) of two-level system is much larger than time of the photons propagation and quantum dynamical interaction with two-level system. Suppose that initial distance between “down” photon and two-level system is larger than sum of the initial distance between “left” photon and two-level system and photon wave packet width, as it is presented at Figure 7. In this case two-level system firstly quantum dynamically interacts with “left” photon. Then two-level system absorbs “left” photon and turns out in excited state as it is presented at Figure 8. Later two-level system quantum dynamically interacts with “down” photon and this interaction can be considered as the
stimulated emission after which two identical photons propagate certainly in “up” direction while two-level system turns out in the ground state as it is presented at Figure 9.

Suppose, however, that initial distance between one photon and two-level system is identical to initial distance between other photon and two-level system as it is presented at Figure 10. (Such situation is very hard for experimental realization, but it is principally possible.) In this case two-level system must simultaneously quantum dynamically interacts with two photons, i.e. two wave packets that totally overlap in time. Two-level system can absorb only one photon and can turn out in excited state but without any quantum dynamical influence at other photon that propagates in the same direction. But, according to suppositions and standard quantum mechanical formalism there is no certain choice which photon will be absorbed, “left” or “down”. According to standard quantum mechanical formalism, after mentioned quantum dynamical interaction between photons and two-level system, quantum super-system than includes both photons and two-level system, is described by the following quantum superposition state

\[
\begin{align*}
2^{1/2} |\text{“up”}\rangle |E\rangle + 2^{1/2} |\text{“right”}\rangle |E\rangle
\end{align*}
\]

(6)  

f(and vice versa) normally presented at Figure 11. First term in (6) corresponds to absorption of the “left” photon and propagation of other “down” photon in the same direction, “up” in respect to two-level system in excited state. Second term in (6) corresponds to absorption of the
“down” photon and propagation of other “left” photon in the same direction, “right” in respect to two-level system in excited state. It can be pointed out that superposition coefficients in both terms are identical. Finally, expression (6) can be simply transformed in

\[ (2^{\frac{1}{2}} |\text{“up”}\rangle + 2^{\frac{1}{2}} |\text{“right”}\rangle) |E\rangle \]

It effectively represents a non-entangled quantum state in which single photon is in quantum superposition of $|\text{“up”}\rangle$ and $|\text{“right”}\rangle$ quantum states or corresponding trajectories, while two-level system is in excited state.

5. 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.

Simply speaking, after quantum dynamical interaction between P and DPP and before quantum dynamical interaction between P and DPP, P is exactly described by quantum superposition state (1). But, except in small vicinity of BS or DPP, reflected and transmitted photon state extremely weakly interfere. It means that, except in mentioned small vicinities, all conditions for self-collapse at P as spontaneous (non-dynamical) unitary symmetry (superposition) breaking (effective hiding) are satisfied so that this self-collapse at P occurs effectively probabilistically at the approximate level of analysis accuracy in full agreement with experimental data (Figure 6.).

But, for $d = 0$, immediately before quantum dynamical interaction between P and DPP, reflected and transmitted photon become strongly interfering. It means that conditions for self-collapse at P becomes non-satisfied at the approximate level of analysis accuracy and mentioned self-collapse disappears at this approximate level of analysis accuracy. Nevertheless, there is exact quantum superposition (1) which will be detected by DPP (Figure 1.).

For $d = d(w)$, as it is not hard to see, P stands in self-collapsed state, i.e. in state of mentioned statistical mixture of reflected and transmitted photon even in moment of the quantum dynamical interaction between P and DPP at the approximate level of analysis accuracy. At the same approximate level of analysis accuracy, mentioned quantum dynamical interaction extends mentioned statistical mixture in corresponding mentioned super-systemic statistical mixture in full agreement with experimental data (Figure 4.). But at the exact level of analysis accuracy mentioned quantum dynamical interaction extends quantum superposition (1) in super-systemic quantum superposition or entangled quantum state (5).

That is all and nothing more is necessary.

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 behavior 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 “continuously” translated in right (in respect to Figure 1. in [7]) , 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].

6. Conclusion

In conclusion the following can be repeated and pointed out. In this work we theoretically considered variations of remarkable experiments of single photon interference (at beam splitter, at diaphragm with two slits, etc., especially recent experiment of such kind realized by V. Jacques, E. Wu, et al.) or (Hong-Ou-Mandel) two photons interference. In mentioned variations intensity of interference or degree of overlap of photon wave packets in superposition can be changed practically continuously (it can “continuously” increase or decrease). It will be correlated with possibility (shortly noted by Feynman) of a practically “continuous” phase transition from detection of the quantum system trajectories superposition (interference) in detection of the quantum system trajectories statistical mixture (and vice versa) in real experiments. All this can be very important for the quantum mechanics foundation since it clearly demonstrates that quantum superposition breaking, i.e. (self)collapse has not necessarily absolute character as well as that it can be realized at micro-systems (photon, electron, atom, etc.). 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. 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. in elasticity of rigid bodies, quantum theory of ferromagnetism, quantum theory of electro-weak interactions as well as in chaotic inflation cosmology.

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