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Schrodinger's Cat State in Two-Slit Interferometer and in Some Macroscopically Distinguishable State.

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Abstract: In the present work we are concerned with the Schrodinger's cat state in Young's two slit interferometer and it has been shown that the photon and the interference pattern are in an entangled state. We have also described few cases in non physics contexts exhibiting Schrodinger's cat state in macroscopic world.
Keywords: Schrodingers cat

I. INTRODUCTION

The present work is concerned with the topic of Schrodinger cat state in quantum mechanics which is still hotly debated among researchers, due to its importance in the quantum theory of measurement. The phenomenon which forms the subject of the present work was described by the author and collaborators in a publication [1] in which the findings of the two slit interferometer experiment and Schrodinger cat states were also discussed. Primarily, in the present work, we make an attempt to correlate three different topics of considerable interest in quantum optics, such as Two-slit interferometer and Quantum interference, Quantum superposition principal and Schrödinger's cat and photon wave function. During discussion we have also described few examples of macroscopically distinguished states which bear a resemblance to or analogous to Schrödinger's cat state. The paper is organized as follows. Section II reviews the Young's double slit interferometer experiment and the topic of quantum interference. We include in this description the interference pattern and particularly the analysis given by Feynman [2] in connection with the appearance and disappearance of interference pattern. This phenomenon is important for our discussion of Schrodinger's cat . Section III specifically discusses the topic of the Schrodinger's cat. The topic of the wave function for photon is reviewed in section IV. In section V we describe the two-slit experiment and Schrodinger cat states and represent them with the help of wave functions. In this section we have also described some macroscopically distinguishable states and construct similar wave functions.

II. YOUNG'S DOUBLE SLIT INTERFEROMETER AND QUANTUM INTERFERENCE.

I this section we discuss the topic of quantum interference in the light of Youngs double slit experiment so as to correlate the topic of Schrodinger cat. It is already known that the two-slit interferometer or two-slit diffraction experiment as it is called equally stands at the centre of the conceptual foundations of quantum mechanics. It has been indicated that the principle of superposition is also at the heart of quantum mechanics. The basic feature of the superposition principle is that the probability amplitudes can interfere, a feature that has no analogue in classical physics. Quantum interference is a challenging principal in quantum theory. Essentially the principle states that subatomic or elementary particles can not only be in more than one place at a give time (through superposition) but an individual particle such as photon, can cross its own trajectory and interfere with the direction of its path. Sir Issac Newton (1642-1726) proclaimed that light consisted of particles (corpuscles) and he clung to this idea through out his life. Similarly Christian Huygens (1629-1695) in the early part of seventeenth century enunciated a convenient principle to describe how every point on a wave front may itself be regarded as a source of secondary waves. Thus if the position of the wave front at any instant is known as simple construction enables its position to be drawn at any subsequent time. Thomus Young (1773-1829) devised the double slit experiment to prove that light consisted of waves. Although the implications of Young's double slit interferometer are difficult to accept it has yielded proof of quantum interference through repeated trials. According to Feynman [2] in a double slit experiment each photon not only goes through both the slits of the experiment, but traverses every possible trajectory, on the way to the target screen. Otherwise it is not possible to explain the formation of the interference pattern. In order to see how this might possible occur, experiments have been focussed on tracking the path individual photons. However, what happens in this case is that the measurement in some way disrupts the paths of the photons in accordance with the uncertainty principle and somehow, the results of the experiment become what would be predicted by classical physics: two bright lines on the photographic screen aligned with the slit. Cease the attempts to measure, the interference pattern will appear again, with multiple lines in varying degrees of brightness and darkness. Again try to measure the path or locate the photon, interference pattern will disappear.

It is worthwhile to indicate here that phenomena of appearing and disappearing of interference pattern in double slit interferometer also show up in some non physics contexts or in macroscopic object. It is worthy of remark here that these examples are brought under discussion as analogies only. Example: The image of any object (say a red rose) formed on the surface of clear and still water can be observed beautifully unless and until it is disturbed. If we cease our attempt to disturb the image will appear again. Another example can be found in the well known creeper plant called " touch me not". When the creeper is touched at any part of the body, it immediately closes its leaves. If it is left undisturbed for some time, the leaves open up again. Touch it again it will die down. The third and also familiar example is a Millipede- a small (about 10 cm long) many legged creature with a long round body. It is noted that whenever one tries to disturb the movement by slightly touching it, it immediately curls its body into a coil and after some time it opens up again. This means that the movement is destroyed by its interaction with an outside environment. But here again it restore its shape after the interaction is withdrawn. It is analogues to the process of Decoherence. The examples given above are quite similar to the phenomenon of quantum interference in the double slit experiment. Quantum interference research is being applied in growing number of application such as Lasing Without Inversion (LWD), superconducting quantum interference device (SQUID), Quantum cryptography and Quantum computing.

III. SCHRODINGER'S CAT

What is Schrodinger Cat ? This is a thought experiment first introduced by Erwin Schrodinger [3] in 1935, to illustrate a paradox in quantum mechanics, regarding the probability of finding a subatomic particle at a specific point in space. In the opinion of Niels Bohr the position of such a particle remains indeterminate until it has been observed. Schrodinger postulated a sealed vessel containing a live cat and a device triggered by a quantum event, such as the radioactive decay of a nucleus. If the quantum event occurs, cyanide (poison) is released and the cat dies; if the event does not occur the cat lives. Schrodinger argued that Bohr's interpretation of event in quantum mechanics means that a cat could only said to be alive or dead when the vessel has been opened and the situation inside it had been observed. The paradox has been extensively discussed since its introduction. It is also thought that the process of decoherence might resolve the paradox in a satisfactory way. Decoherece is a process in which the quantum mechanical state of a system is altered by the interaction between the system and environment.

A variation of Schrodinger's cat paradox is the Wigner's friend. In this particular case a friend of the physicist Eugene Wigner (1902-1905) is the first to look inside the vessel. The friend will find either alive or dead cat. However if professor Winger has both the vessel with the cat and the friend in a closed room, the state of mind of the friend (Happy if the cat lives and sad if there is a dead cat) cannot be determined in Bohr's interpretation of quantum mechanics until the professor has looked into the room although the friend has already looked at the cat. These paradoxes indicate the overstate roles of measurement and observation in Bohr's interpretation of quantum mechanics.

Schrodinger cat states may be represented by an important type of single mode field state having strong non classical properties. We consider here a class of states consisting of superposition of two coherent states of equal amplitude but separated in phase by 180^0 , that is states of the form

$$|\Psi\rangle = N\left(|\alpha\rangle + e^{i\Phi}|-\alpha\rangle\right) \text{......................(1)}$$

Where the normalization factor N is given bis given by

$$N = \left[2 + 2\exp(-2\alpha^2)\cos\Phi\right]^{\frac{1}{2}} \text{.....................(2)}$$

Where α is real. For large $|\alpha|$ the states $|\alpha\rangle$ and $|-\alpha\rangle$ are macroscopically distinguishable and superposition of the form of equation (1) are frequently referred to as the Schrodinger's cat state. It may be noted that Schrodinger's cat state was to end up in a superposition of macroscopically distinguishable states, that is, the states of being alive and of being dead. It is worthwhile to emphasize that Schrodinger's purpose was not to demonstrate how quantum strangeness could be visualized in the everyday classical world but rather to use the cat paradox as a satire the Copenhagen interpretation of quantum mechanics, which he and many others including Einstein thought absurd. In recent years, however, it has become possible to consider the laboratory realizations of the superposition of quantum states that are in some way macroscopically distinguishable. The following question is the driving force behind the works to know the boarder between the quantum mechanical and classical world. Superposition states of the form of equation (1) are never seen in the microscopic world. But, it is worthy of remark that no quantum system, particularly a macroscopic one, is truly an isolated system; it invariably interacts with the rest of the universe, the environment involves

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innumerable degree of freedom which are not observed, although in some sense, the environment "observed" the system effectively interacting with it in a dissipative fashion. In reality, the entire universe is quantum mechanical and when a small part of it interacts with the rest, the two subsystems become entangled. If may be shown [4] that tracing out the variables of the unobserved part of entangled system leaves the system of interest in a mixed state. Thus if a coherent macroscopic superposition state of the form of equation (1) can be created somehow and it once, de-coheres into a statistical mixture of the form

$$\hat{P} = \frac{1}{\sqrt{2}}\left(|\beta\rangle\langle\beta| + |-\beta\rangle\langle-\beta|\right) \quad ....(3)$$

where $\beta = \alpha e^{-\frac{\gamma t}{2}}$ and γ is related to the rate of energy dissipation. It may be noted that the more macroscopic the components of initial superposition state, that is, the greater |α| the more rapid should be the decoherence. It is worthwhile to distinguish between superposition states and statistical mixtures, the latter having properties that are only classical.

We have three important cal states, depending on the choice of relative phase ϕ. For ϕ=0 we obtain the even coherent states

$$|\Psi_e\rangle = N_e\left(|\alpha\rangle + |-\alpha\rangle\right) \quad ....(4)$$

For ϕ=π, we obtain the odd coherent states

$$|\Psi_o\rangle = N_o\left(|\alpha\rangle - |-\alpha\rangle\right) \quad ....(5)$$

Where

$$N_e = \frac{1}{\sqrt{2}}\left[1 + \exp(-2\alpha^2)\right]^{-\frac{1}{2}} \quad ....(6)$$

$$N_o = \frac{1}{\sqrt{2}}\left[1 - \exp(-2\alpha^2)\right]^{-\frac{1}{2}} \quad ....(7)$$

are the respective normalization factors. These sates were first introduced by Dodonov et. al [4], Buzek et. Al [5] and Gerry [6]. For $\phi = \frac{\pi}{2}$, we have Yurke – Stoler states [7].

$$|\Psi_{ys}\rangle = \frac{1}{\sqrt{2}}\left(|\alpha\rangle + i|-\alpha\rangle\right) \quad ....(8)$$

All three states are eigenstates of the square of the annihilation operator with α^2 as the eigenvalue :

$$\widehat{a^2}|\Psi\rangle = \alpha^2|\Psi\rangle \quad ....(9)$$

IV. PHOTON WAVE FUNCTION

The topic of this section is chosen primarily because of its relation with the topic of interference with the double slit interferometer and Schrodinger's cat. Strictly speaking there is no such thing as a photon wave function. But there are evidence and arguments for and against the concept of photon wave function [8]. In this connection we would like to refer to the article of Sudarshan and Rothman [9] where it has been shown that the standard exposition of the two slit interferometer or two slit diffraction experiment is incorrect because it treats the interference as arising from the photon wave function ψ, whereas the interference is really between coherent states of the field, which do not correspond to single photon states. We may also note here that the topic "Wave function for photon" is a leading topic in a section of power's book on Quantum Electrodynamics [10]. Powers and Kramers[11] are of the opinion that one may not think of a photon in the same sense as a massive (non-relativistic) particle. Some physicists argued that a single photon in free space is analogous to meson if we let the meson mass go to zero. DeBroglie created the idea of wave-particle duality and accordingly he suggested that the electron might display wave like behaviour. However, from the perspective of Quantum Optics the wave mechanical, Maxwell-Schrödinger treatment makes a clear distinction between light and matter waves. According to Scully [8] the conclusions of Kramer's regarding the wave function of photon may be marginally true and each of the objections may be overcome. This is done in the semi classical theory of laser as shown in Table 1.

As shown in Table 1, the semi classical theory of the radiation and matter fields are treated according to the Maxwell and Schrodinger equations. Both fields display wave like behaviour but ħ appears only in the matter equations. Applying the full quantum theory e.g. Dirac and Schwinger, the radiation and matter are treated on the same footing.

Table

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	Light	Matter
SEMICLASSICAL	$E(r,t)$ $\square^2 E = -\mu P$	$\Psi(r,t)$ $\dot{\Psi}(r,t) = \frac{-i}{\hbar} H \Psi(r,t)$
QUANTUM FIELD	$\|\dot{\Psi}_f\rangle = \frac{-i}{h} H_f \|\Psi\rangle$ $E(r,t) = \sum_k \omega_k(t) U_k(r)$ Dirac	$\|\dot{\Psi}\rangle = \frac{-i}{\hbar} H_m \|\Psi_m\rangle$ $\dot{\Psi}(r,t) = \sum_p c_p \Phi_p(r)$ Schwinger

V. YOUNGS DOUBLE SLIT INTERFEROMETER AND SCHRODINGER'S CAT.

We now consider the interference pattern in Young's double slit interferometer in the light of our discussion of Schrodinger's Cat. Let us first consider the entangled state between two coherent states given by [ ]

$$|\Psi\left(\frac{\pi}{2x}\right)\rangle = \frac{1}{\sqrt{2}}\left(|g\rangle|i\alpha\rangle + i e^{i\Phi}|e\rangle|-i\alpha\rangle\right) .... (10)$$

It may be noted that in terms of phase space picture, the two coherent states in Eqn (10) are separated by 180^0, the maximum separation. Coherent states differing in phase by 180^0 are also maximally distinguishable in the sense that there is essentially no overlap between the two states, at least if |α| is large enough. In fact this is the case even with |α| as low as $\sqrt{2}$. With very large value of |α| the two coherent states are said to be macroscopically distinguishable and, for moderate values mesoscopically distinguishable. The entangled state of Eqn (10) might bring in to picture of Schrodinger's ill-fated cat, suspended in a state of limbo, suspended in an entanglement between life and death and a non-decayed or decayed radio active microscopic atom. Symbolically, the entangled state in schrodinger's "paradox" is thus:

$$|\Psi_{atom-cat}\rangle = \frac{1}{\sqrt{2}}\left[|atom\ not\ decayed\rangle|cat\ alive\rangle + |atom\ decayed\rangle|cat\ dead\rangle\right] ... (11)$$

The parallel between this state and that of eqn (10) is obvious, the states of the two leve atom play the role of the radioactive atom and the two phase-separated coherent field states that of the cat. According to Gerry and Knight [12], the paradigm of Schrodinger's cat is like that of Einstein, Podolsky and Rosen (EPR) paradox[13] of 1935. But Schrodinger's cat paradox is not a paradox at all, it is a phenomenon. Though historically this paradox is often dismissed as having no observable consequences, this position can no longer be maintained. Noel and Stroud [14] have generated radial Schrodinger cat state in a Rydberg atom with average principal quantum number 65. Two radial wave packets are created that can be separated by as much as 0.4 μm. Although the word and entanglement was first used by Schrodinger to describe state of this short the concept certainly appears in the EPR paper[13] and the paper certainly inspired Schrodinger's remark, Schrodinger's paradox is certainly true of the original formulation.

In our opinion in the case of double slit experiment the photon and the interference are in an entangled state of the form

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left[|photon\ observed\rangle|interference\ destroyed\rangle + |photon\ not\ observed\rangle|interference\ observed\rangle\right] .... (12)$$

In the case of the macroscopic and non-physics contexts described in an earlier section II, we have

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left[|water\ not\ disturbed\rangle|image\ live\rangle + |water\ disturbed\rangle|image\ dies\rangle\right] .... (13)$$

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left[|millipede\ is\ touched\rangle|movement\ dies\rangle + |millipede\ is\ not\ touched\rangle|movements\ exist\rangle\right] .... (14)$$

Similarly in the case of the creeper "touch me not" we have the wave function representing the entangled state of the form.

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left[|creeper\ not\ touched\rangle|creeper\ lives\rangle + |creeper\ is\ touched\rangle|creeper\ dead\rangle\right] .... (15)$$

The parallel between the state given by Eqn(11) and that of eqn (12) to Eqn (15) obvious. In case of Eqn (12) the role of photon plays the role of radioactive photon and the interference pattern that of the cat. In Eqn (13) the role of the undisturbed water plays

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the role of the radioactive atom and image that of the cat. In Eqn (14) the role of the millipede plays the role of the body movement represents the cat. Similarly in Eqn (15) the role of the creeper plays the role of the radioactive atom and the movement of the creeper represents the cat. We may indicate here that the analogies taken from the non-physics contexts may be appropriately referred to as Schrodinger's cat state macroscopic world.

VI. SUMMERY AND CONCLUSIONS

In the present work we are concerned with the topic Schrodinger's cat state. Specifically we have considered the phenomenon of quantum interference in Young's double slit experiment and shown that photon and the interference patterns are in an entangled state of the form.

$$|\Psi\rangle = \frac{1}{\sqrt{2}}[|photon\,observed\rangle|interference\,destroyed\rangle + |photon\,not\,observed\rangle|interference\,observed\rangle]$$

Which is similar to that Copenhagen interpretation of Schrodinger's cat(dead or alive) in an entangled state of the form of wave function.

$$|\Psi_{atom-cat}\rangle = \frac{1}{\sqrt{2}}[|atom\,not\,decayed\rangle|cat\,alive\rangle + |atom\,decayed\rangle|cat\,dead\rangle]$$

We have also few cases in non-physics domain exhibiting Schrodinger's cat state in macroscopic world. It is reasonable to believe that there are many examples in macroscopic world where Schrödinger cat states are observed.

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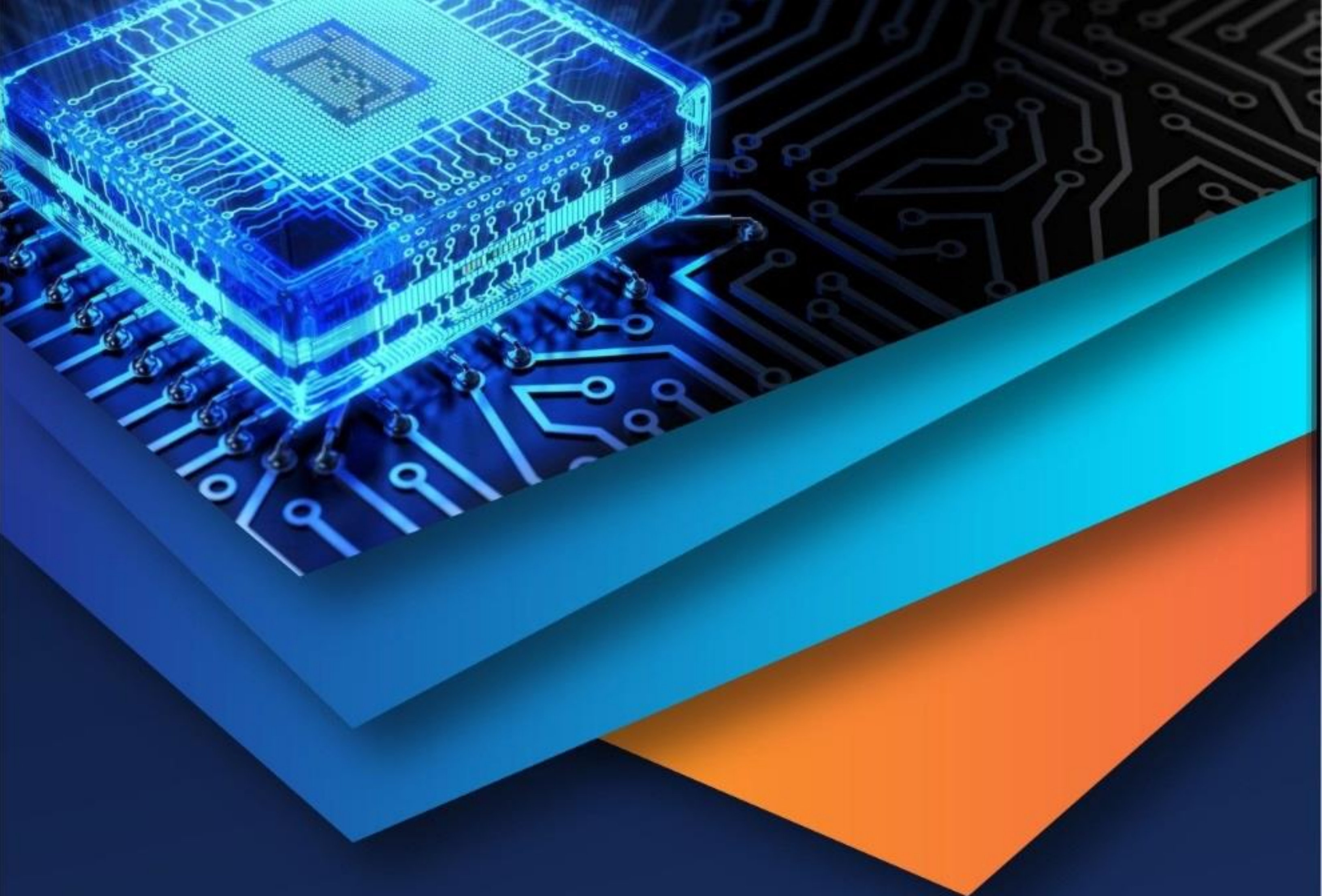

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