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# An analysis of Young's double slit experiment in the light of Schrodinger's cat.

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## ABSTRACT

*Quantum interference is a challenging phenomenon in quantum optics. According to this principle of superposition of quantum mechanics, elementary particles such as photon can not only be in more than one place at a given time, but that an individual particle can cross its own trajectory and interfere with the direction of its path. Thomas Young devised the double slit experiment to prove that light consisted of waves. Analysis of the double slit experiment and the interference pattern indicates that each photon not only goes through both the slits simultaneously, but traverses every possible trajectory on the way to the target, not just in theory, but in fact. In the present work we have analysed the situation in terms of quantum superposition and Schrödinger cat states in quantum optics. The nature of photon in this analysis is examined.*

**Keywords:** Schrodinger's cat,

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## INTRODUCTION

In the present work we make an attempt to correlate three different topics of considerable interest in quantum optics. They are Young's double slit experiment and quantum interference, quantum superposition's and Schrödinger's cat state and photon wave function. It is worthwhile to note that these topics have attracted attention among research workers due to their importance in the theory of measurement. It is generally accepted that the quantum theory of radiation provides a reasonably complete description of radiation matter interactions. Photons are quanta of a single monochromatic mode of the radiation field and are not localised at any particular position and time within the cavity like fuzzy balls; rather they are spread out over the entire cavity. In fact no satisfactory quantum theory of photons as particles has ever been given. On the other hand the quantum theory of radiation seems to offer amazingly satisfactory accounts of a very wide range of radiative problems and, therefore, there is no real need to have a corpuscular theory of photons [1]. However, advances in quantum optics have brought forward new arguments for quantizing the electromagnetic field, and with them deeper insight into the conceptual nature of photons.

In this paper we present a pedagogical review of the principle of superposition in the light of the phenomenon of interference in Young's double slit experiment. Schrödinger cat states in quantum optics are also brought into the discussion.

## MATERIALS AND METHODS

### 2. Schrödinger's Cat:

What is Schrödinger's cat? This is a thought experiment first introduced by Erwin Schrödinger in 1935 to illustrate a paradox in quantum mechanics regarding the probability of finding a subatomic particle at a specific point in space

[2]. According to Neil's Bohr the position of such a particle cannot be determined until it has been observed. Schrödinger 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 is released and the cat dies. If the event does not occur the cat lives. Schrödinger argued that Bohr's interpretation of events in quantum mechanics means that the cat could only be said to be alive or dead when the vessel has been opened and the situation inside it had been observed. This paradox has been extensively discussed since its introduction. It is generally thought that the concept of decoherence may resolve the paradox in a satisfactory way. Decoherence is a process in which a quantum mechanical state of a system is altered by the interaction between the system and the environment. Decoherence was postulated in the 1980's and has been used to clarify discussions of the foundations of quantum mechanics and problems of measurement.

## 3. Quantum interference and Young's double slit experiment:

In this section we discuss the topic of quantum interference from the point of view of the double slit interference of Thomas Young. It has often been indicated that the principle of superposition is at the heart of quantum mechanics. The basic feature of the superposition principle is that probability amplitudes can interfere, a feature that has no analogue in classical physics. Quantum interference is a challenging principle of quantum theory. Essentially the principle states that elementary or subatomic particles can not only be in more than one place at a given time (through superposition) but an individual particle such as photon, can cross its own trajectory and interfere with the direction of its path. Debate over whether light is essentially particles or waves dates back over three hundred years. In seventeenth century, Sir Isaac Newton (1642-1726) proclaimed that light consisted of particles and he clung to this throughout his life. Similarly Christian Huygens (1629-1695), in the early part of seventeenth century enunciated a convenient working principle to describe how the progress of the primary wave front of a source of light is due to the generation of secondary wavelets from every point of the primary wave front. Thomas Young (1773-1829) devised the double slit experiment to prove that it consisted of waves. Although the implications of Young's experiment are difficult to accept, it has reliably yielded the proof of quantum interference through repeated trials. Thomas Young, in 1801 first demonstrated the interference effect of light. In this experiment (not the original one) a beam of light is aimed at a barrier with two vertical slits. The light passes through the slits and the resulting pattern is recorded on a photographic plate. If one slit is covered, the pattern would be a single line of light, aligned with whichever slit is open. Intuitively one would expect that if both slits are open, the pattern of light will be two lines of light aligned with the slits. In fact, however, what happens is that the photographic plate is entirely separated into multiple lines of lightness and darkness in varying degrees. What is being illustrated by this result is that interference is taking place between the waves or particles going through the slits, in what, seemingly should be two non-crossing trajectories. It would be expected that if the beam of photons is slowed enough to ensure that the individual photons are hitting the plate, there would be no interference and the pattern of light would be two lines of light aligned with the slits. In fact, however, the resulting pattern still indicates interference, which means that somehow the single particles are interfering with themselves. This appears impossible. We expect that a single photon will go through one slit or the other, and will end up in one of the two possible light line areas. But this is not what is happening. According to Feynman [3] each photon not only goes through both slits, but simultaneously traverses every possible trajectory, on the way to the target, not just in theory, but in fact. In order to see how this might possibly occur, experiments have focused on tracking the paths of individual photons. What happens in this case is that the measurement in some way disrupts the trajectories of photons in accordance with uncertainty principle, and somehow, the results of the experiment become what would be predicted by classical physics: two bright lines on the photographic plate, aligned with the slits in the barrier. Cease the attempt to measure; the interference pattern will again appear with multiple lines in varying degrees of lightness and darkness.

It is worthwhile to indicate there that the quantum interference phenomenon appearing here show up also in non-physics contexts in macroscopic objects. It should be emphasized, however, that these examples are brought into the discussion as analogy only. Examples: The image of any object formed on the surface of a clear and still water can be seen beautifully unless and until it is disturbed. If we cease our attempt to disturb, the image will again appear. Another example can be found in a well known Creeper plant called "touch me not". When the plant 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. Cease the attempt to touch the leaves it will return to its original shape. These are quite analogous to what has been described above in connection with the phenomenon of quantum interference.
Quantum interference research is being applied in a growing number of applications such as superconducting quantum interference device (SQUID), quantum cryptography, quantum computing and lasing without inversion (LWI)

## 4. Wave function for photon

The topic of this section is chosen primarily due to our discussion about Schrödinger's cat and double slit experiment. Strictly speaking, there is no such thing as a photon wave function. But there are evidence and arguments for and against the concept of a photon wave function [4]. It is worthwhile to note that ‘wave function for photons’ is the heading of a section in Powers classic book on Quantum Electrodynamics [5]. Power and also Kramer’s [6] are of the opinion that one may not think of the photon in the same sense as a massive (non relativistic) particle. On the other hand some physicists argue that a single photon in free space is analogous to meson if we let the meson mass go to zero. The wave-particle duality of light was the notion created by De-Broglie which led him to suggest that 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 wave. The interference and diffraction of matter waves are the essence of quantum mechanics. But the corresponding behaviour of light is described by the classical Maxwell’s equations. The question naturally arises; can we think of the electric field of light as a kind of wave-function for the photon. Specifically in his book on quantum mechanics Kramer raises the question in the section entitled “The photon Wave Function: Motivation and Definition,”.....Now that wave mechanics has been become a consistent formalism one could ask whether it is possible to consider the Maxwell’s equation to be a kind of Schrödinger equation for light particles, instead of considering them, as we have done up to now , to be classical equations of motion which formally look like a wave equation, and which are quantized only later on; or both ideas are equivalent?

At the end of the section Kramer answers the question as follows:
The answer to the question put at the beginning of this section is thus that one can’t speak of particles in a radiation field in the same sense as in the (non-relativistic) quantum mechanics of systems of point particles.

Kramer’s reason for this conclusion is the same as that clearly stated by Power (5) who says (in section 5.1 entitled ‘ wave function for photons’).

Thus it is natural to ask what are the ϕ·s for photons. Strictly speaking there is no such wave functions. One may not speak of particles in a radiation field in the same sense as in the elementary quantum mechanics of systems of particles. The reason is that the wave equation............. solutions of Schrödinger’s time-dependent wave function corresponding to an energy $E_\lambda$ have a circular frequency $\omega_\lambda=+E_\lambda/\hbar$, while the monochromatic solutions of the wave equation have both ± $\omega_\lambda$.

The E and B fields satisfying the Maxwell’s equations in free space and therefore satisfying the wave equations too , are real and are not eigen functions of iħδ/δt. A Schrödinger wave of given energy must be complex. The real electric wave like

$$E(\vec{r},t)=\sum_k \hat{\in}_k\, \Sigma_k a_k \exp\overset{\wedge}{\left[-iv_k t+i\vec{k}.t\right]}+H.C$$

was both exp(-i $\nu_k$ t) and exp( i $\nu_k$ t) parts while the matter wave has only exp(-i $\nu_p$ t) type terms. Boehm in his classic book Quantum Theory (page 98) notes that

> The probability that an electron can be found with position between x and x+dx is

$$P(x)=\Psi^*(x)\Psi(x)dx$$

He then compares this with the situation for light and goes on to say:

There is, strictly speaking no functions that represents the probability finding a light quantum at a given point. If we choose a region large compared with a wavelength, we obtain approximately

$$P(x)\approx\frac{\Sigma^2(x)+K^2(x)}{8\pi\hbar\nu(x)}$$

But if this region is defined too well, ν(x) has no meaning.
Later on Bohm make the statement that for matter there is a probability current

$$S=\frac{\hbar}{2mi}(\Psi^*\Delta\Psi-\Psi\Delta\Psi^*)$$

Monroe et.al[12] have generated even and odd coherent states as well as Yarke-Stoler states for the quantized vibrational motion of a single traped ions. With an average of about nine vibrational quantum wave packets of maximal spatial separation of about 83nm significantly larger than the size of a single component wave function in the superposition, about 7nm were obtained. These superpositions are obviously non macroscopic but do approach being macroscopic and therefore may be taken as a realization of the schrodinger cat phenomenon.

It has often been said that the principle of superposition is at the heart of quantum mechanics. In classical physics we do not speak of superpositions of possible states of a system, rather we assume that the physical attributes of a system objectively exist even if unknown. But in quantum mechanics it appears necessary to abandon the motion of an objective local reality[13]. Instead a quantum system is described by a state vector which may be expanded into a coherent superposition of the eigenstates of some observable.

$$\left|\Psi\right\rangle = \sum C_i / \Psi_i \rangle \text{..........................................(1)}$$

Where the coefficients $C_i$ are probability amplitudes. The probability that a measurement of that observable finds the system in state $\left|\Psi\right\rangle$ is $\left|C_i\right|^2$. But the state vector of Eq.(1) is not merely a reflection of our ignorance of the true state of the system before a measurement but rather of its objective indefiniteness. The system has no objectivity definite state prior to a measurement. The act of measurement “collapses” the state vector to one of the eigenstates. The basic feature of superposition principle is that probability amplitudes can interfere that has no analog in classical physics.

We now consider the Young’s double slit interference pattern in the light of our discussion of Schrödinger’s cat. According to the Copenhagen interpretation, the atom and the cat are in an entangled state of the form of wave function.

$$\left|\Psi\right\rangle = \frac{1}{\sqrt{2}}[\left|atom\,not\,decayed\right\rangle\left|cat\,alive\right\rangle + \left|atom\,decayed\right\rangle\left|cat\,dead\right\rangle \text{.............................(2)}$$

Which satisfies the relation

$$\frac{\delta p}{\delta t} + divS = 0$$

But he notes that there is no corresponding quantity for light.

According to Scully [4] the above conclusions of Kramer’s and Boehm regarding the wave functions of photon may be marginally true and each of the objections may be overcome. This is done in the semi classical theory of laser [1], as shown in Table 1.

**Table 1**

| | Light | Matter |
|---|---|---|
| Semi classical | $E(\vec{r}, t)$<br>$\square^2 E = -\mu_o \vec{p}$<br>Maxwell | $\Psi(\vec{r}, t)$<br>$\Psi\,\dot{\Psi}(\vec{r},t) = -\frac{i}{h} H\Psi(\vec{r},t)$<br>Schrödinger |

As shown in Table 1 the semi classical theory of radiation and matter “fields” are treated according to the Maxwell and Schrödinger equations. But field display wavelike behaviour but ħ appears only in the matter equation.

## RESULTS AND DISCUSSION

From the discussion above it is now appropriate to make some observation on Schrödinger's cat and Young interference fringes, the main objective of our paper. According to Gerry and Knight [8], the paradigm of Schrödinger's cat is, like that of Einstein, Podolsky and Rosen(EPR) [9], often presented as though it were a paradox, (particularly so so in some of the popular literature on the subject) [10]. But Schrödinger's cat paradox is no paradox at all, it is a phenomenon. Historically this paradox has often been dismissed as having no observable consequences. Such a position can no longer be maintained. It may be noted that cat like states have been generated in different contexts. Noel and Stroud [11] have generated radial Schrodinger's 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 entanglement was used first by Schrödinger to describe states of this sort the concept certainly appears in the paper of Einstein, Podolsky and Rosen (EPR) [9] the paper that inspired Schrödinger's remarks. In any case upon opening the box the state vector collapses to one state or the other in the superposition. Schrödinger refers to this as a "quite ridiculous case". But Schrödinger's paradox certainly true of the original formulation. In case of double slit experiment the photon and the interference are in an entangled state of the form

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left[\, \left| \textit{photon not observed} \right\rangle \left| \mathrm{int}\, \textit{ererference yes} \right\rangle + \left| \textit{photon observed} \right\rangle \left| \mathrm{int}\, \textit{erference destroyed} \right\rangle \right] \ldots\ldots(3)$$

In the case of a macroscopic and non physics example described in section 3 we have

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left[ \left| \textit{water not disturbed} \right\rangle \left| \textit{image exists} \right\rangle + \left| \textit{water disturbed} \right\rangle \left| \textit{image dead} \right\rangle \ldots\ldots\ldots\ldots(4) \right]$$

We wish to indicate here that the analogies of non physics contexts may be referred to as Schrödinger cat states in macroscopic level.

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