

# Einstein's Relativity, Simultaneity and Young's Double Slit Experiment

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## ABSTRACT

In the present work we have discussed the well known topic of simultaneous passing of photon through both the slit of Young double slit experiment. With the help of the example of Newton's sailor in the special theory of relativity we have shown that Feynman's statement in the quantum version of Young's double slit experiment regarding the simultaneous passage of a photon through both the slits simultaneously needs to be qualified.

## 1. Introduction

In the present work we shall concern ourselves with three topics of interest: Einstein's Relativity, Simultaneity and Young's double slit experiment. It is worthwhile to note here that the description of Young's double slit experiment and the process of interference is easily available in most of the text books of Optics. In the seventeenth century, Sir Isaac Newton (1642-1726) proclaimed that light consisted of particles. In the early part of seventeenth century, Christian Huygens (1629-1695) enunciated a convenient principle to describe how the progress of the primary wave from a source of light is due to the generation of the secondary wavelets from every point of primary wavefront. We may indicate here that Sir Isaac Newton could not measure the mass of the corpuscles, but Huygen could measure the wavelength of the light waves. Thomas Young devised the double slit experiment to prove that light consisted of waves. It is worthwhile that we introduce the topic of quantum interference which is so important from quantum mechanical point of view. The topic of quantum interference has already led to many counterintuitive phenomena like lasing without

inversion, coherent trapping etc. The concept of quantum interference states that the elementary particles such as photons can not only be 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. Although the implications of Young's double slit experiment are difficult to accept, it has already produced reliable proof of quantum interference through repeated trials. In the present work we shall attempt to correlate three specific issues of interest and we believe they do provide additional information for the process of quantum interference in Young's double slit experiment.

The topics of interest which we propose to correlate are the phenomenon of simultaneity as it appears in Einstein's special theory of relativity, photon passing through the double slit simultaneously in Young's experiment and quantum interference.

## 2. Classical Interference of Light Waves

For convenience we describe the standard double slit interference experiment which will be related to Newton's example of sailor in a section to follow. The standard double slit experiment is shown in Fig:1, in which monochromatic light waves are normally incident on two narrow parallel slits which are at a distance  $d$  apart. The light from the two distance  $D$  apart behind them ( $D \gg d$ ). We may consider some point on the screen which is located at a distance  $y$  from the central line as shown in figure. Light from the first slit travels a distance  $x_1$  to get to this point, whereas the light from the second slit travels a slightly different distance.

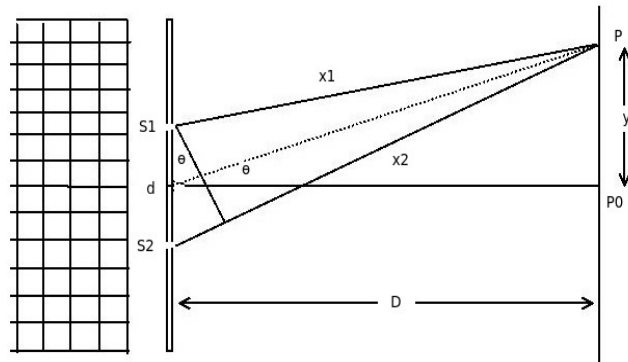


Fig 1. Classical double slit interference of light

It is essential to evaluate the phase difference in terms of the distance  $y$  on the screen from a central point  $P$ , the separation  $d$  of the two slits and the distance  $D$  between the slits and the screen. From simple geometrical consideration as indicated in Fig 1, one can find an expression for the path difference as

$$\Delta x = x_2 - x_1 = \frac{d}{D}y, \text{ provided } d \ll D \text{ --- (1)}$$

$$\Psi(y, t) \equiv \Psi_1 e^{ikx_1} + \Psi_2 e^{ikx_2} \text{ --- (2)}$$

Where  $\Psi_1$  and  $\Psi_2$  are the wave functions at the first and second slits, respectively. Since the slits are illuminated by in phase light waves of equal amplitudes we have

$$\Psi_1 = \Psi_2 \text{ ..... (3)}$$

It may be noted that we are ignoring the differences in amplitude of the waves from the two slits at the screen due to the slight difference between  $x_1$  and  $x_2$  compared to the difference in their phases. This is reasonable provided  $D \gg \lambda$ .

The intensity (or the energy flux) of the light at some point  $P$  of the projection screen is approximately equal to the energy density of light at this point times the velocity of light (provided that  $y \ll D$ ). Hence it follows that the intensity on the screen at a distance  $y$  from the central line is given by

$$I(y) \equiv |\Psi(y, t)|^2 \text{ --- (4)}$$

Using equation (1) – (4) we find

$$I(y) \equiv \cos^2 \left( \frac{k\Delta x}{2} \right) = \cos^2 \left( \frac{kd}{2D}y \right) \text{ --- (5)}$$

If we write the expression for phase difference  $\delta$  as

$$\delta = \frac{2\pi}{\lambda} \Delta x = \frac{2\pi}{\lambda} \frac{d}{D}y = \frac{2\pi}{\lambda} (x_2 - x_1)$$

Equation (5) may be put in the form

$$I \equiv \cos^2 \left( \frac{kd}{2D}y \right) \equiv \cos^2 \frac{\delta}{2} \text{ ..... (6)}$$

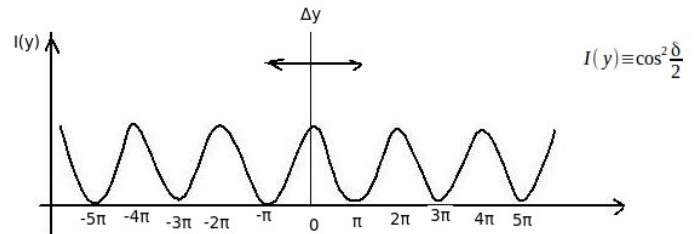


Fig 2: Classical double slit interference pattern

Fig: 2 shows the characteristics interference pattern which corresponds to the expression (6). This pattern consist of equally spaced light and dark bands of characteristics width

$$\Delta y = \frac{D\lambda}{d} \text{ ..... (7)}$$

With this introduction of the classical interference of light wave we proceed to discuss the topic of the quantum interference of light waves in Young’s double slit experiment in the section to follow.

### III. Quantum interference of light waves in Young’s double slit experiment.

According to Feynman the essentials of quantum mechanicals could be grasped from an explanation of the double slit experiment. What is actually happening in the double slit experiment is clearly described by Feynman (9) and also by others. In the double slit experiment, if one slit covered the pattern is what would be expected, a single line of light ( image of the slit ) aligned with whatever slits in open. One would expect that if both slits are open the pattern of light will reflect the fact, two lines of light, aligned with the slits. In fact, however, what happens is that the photographic film as the projection screen is entirely separated into multiple lines with alternate dark and bright intensities. This is what is known as interference, taking place between waves or particle going through the slits, in what seemingly should be two non crossing trajectories. We would expect that if the beam of photons is slowed enough to ensure that

individual photons (or so called antibunched photons) are hitting the photographic film, 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 patterns still indicates interference, which means that somehow, the single photons are interfering with themselves. This seems impossible; because we expect that a single photon will go through one slit or other and will end up in one of the two possible light line areas. But this is not what is happening. According to Feynman each photon not only goes through both the slits simultaneously but traverses every possible trajectories on the way to the target just not 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 these cases that measurements in some way disrupts the photon trajectories (in accordance with uncertainty principle), and somehow, the results of experiments become what would be predicted by classical physics. The double slit experiment stands at the centre of the conceptual foundations of quantum mechanics. A close examination of the standard exposition reveals several conceptual errors and ambiguities. This is primarily due to confusion between the electromagnetic field amplitude and the amplitude of the quantum mechanical wave function. It is shown that this standard exposition of the double slit experiment is incorrect because it treats the interference as arising from the photon wave function  $\psi$ , whereas the interference is really between coherent states of the field which do not correspond to single photon states.

IV. Einstein's relativity, Simultaneity and Young's double slit experiment:

In the earlier section we have discussed the topic of simultaneous passing of a photon through both the slits of a Young's double slit experiment. We shall concern ourselves in the present section with the following questions. Is the concept of simultaneous passing of a photon through both the slits is really true. What is its relation with the old idea of simultaneity that is dethroned by Einstein's special theory of relativity. We would like to discuss this topic and correlate it later in this section with the topic of simultaneous crossing of a photon through both the slits.

The problems created by linking Einstein's two assumptions the similarity of all natural laws for all observers and the constancy of the speed of light in both the electromagnetic and the mechanical worlds

become evident when one considers Newton's handy sailor. Consider the Newtons handy sailor standing on the deck as his ship sails parallel to a long jetty. At each end of the jetty there stands a signal lamp and midway between the two lamps there stands an observer. As the sailor passes the observer, flashes of light are sent out by the two lamps. They are sent out by the two lamps. They are sent out, so far as the stationary observer on the jetty is concerned at exactly the same time. The light rays coming from each end of the jetty have to travel the same distance to reach him and they will reach him simultaneously. But what about the sailor on the ship who will have been at an equal distance from each lamps as each sent out its light signal. We know that both flashes travel with the same speed ( $= c$ ). Although this speed is great it is finite and since he is moving away from one lamp and towards the other he will receive the light signals at different times. Thus as far as the sailor is concerned he will receive the light signals at different times and they will not have been switched on simultaneously. Thus we have the first extraordinary result of linking Einstein's two assumptions. They are correct, and the old idea of simultaneity is dethroned, for events which are not simultaneous to the observer on the jetty are not simultaneous to the sailor on deck. Thus in the words of Einstein "That we cannot attach any absolute signification to the concept of the simultaneity, but two events which viewed from a system of coordinate, are simultaneous, can no longer be looked upon as simultaneous events when envisaged from a system which is in motion relativity to that system". Thus the nub of special theory of relativity rests in the realization that one man's "now" is another man's "then" and "now" itself is a subjective idea valid only for an observer within a specific frame of reference. Now we find it reasonable to believe that what has been stated above is equally true in the case of Young's double slit experiment which includes the quantum version. In the double slit experiment in the language of Feynman "If you have an apparatus which is capable of telling which hole the electron goes through..... then you can say that it goes through one hole or the other. It does, it is always going through one hole or the other when you look..... But when you have no apparatus to determine through which hole the thing goes and then you cannot say that it goes through one hole or the other..... To conclude that it goes through one hole or the other when you are not looking is to produce an error in prediction".

Now we consider the situations arising in Newton's sailor (illustrating the concept of simultaneity) and Young's double slit experiment is shown in the figure 3 (a, b).

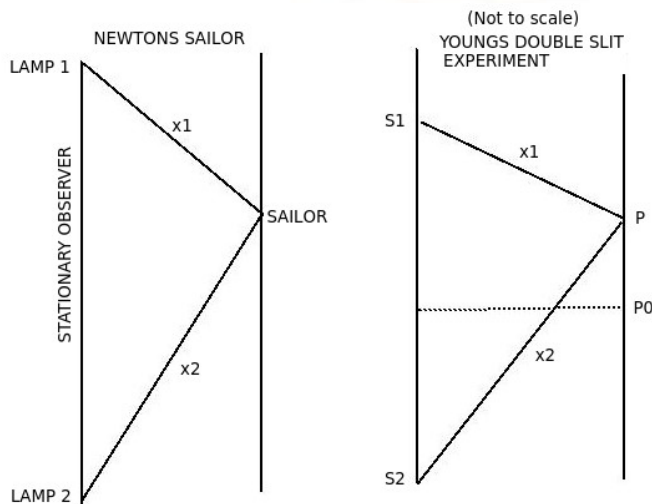


Fig 3. (a) Newton's sailor illustrating the concept of simultaneity and its validity in different coordinate systems (b) Young's double slit experiment as an analogous situation

It is worthy of remark that in Fig: 3 b, the double slit experiment is not shown up to the scale for comparison with Newton's handy sailor, we note that the point P at a distance y from the centre P... Exhibits bright fringes when

$$y = m\lambda \frac{D}{d}, m = 0,1,2,3,\dots$$

And dark fringes when

$$y = \left(m + \frac{1}{2}\right) \lambda \frac{D}{d}$$

In this case we may assume Newton's sailor in Fig:3 a corresponds to an observer at P which is presumably at different distances from the slits S1 and S2. Here we find that a photon which simultaneously passes through both the slits (S1 and S2) according to an observer at the middle point M is not simultaneous according to the observer located at P, because a phase difference has already been introduced. Thus we believe that Feynman's statement that "a photon not only passes through the two slits simultaneously but also crosses its own trajectory on the way to the target" needs to be qualified.

### 3. Summary and Conclusion

In the present work we have discussed the well known topic of simultaneous passing of a photon through both the slits of a Young's double slit experiment. It is possible to obtain (antibunched) a single photon between the slit and the projection screen at any time by making the source extremely weak. In the quantum version of the double slit experiment it has been shown that by sending one photon at a time through the slits does not make any difference to the resulting interference pattern. This led Feynman to remark that a photon crosses both the slits simultaneously. With the help of the example of Newton's sailor in special theory of relativity (and the words of Einstein) we cannot attach any absolute significance to the concept of the simultaneity. Thus it is reasonable to believe that Feynman's statement in the quantum version of Young's double slit experiment regarding the passing of a photon through both the slits simultaneously needs to be qualified.

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