The wave function as a mathematical description of a free particle’s possible motion:

The 2-slit problem with attempted detection

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Abstract

Starting with a down to earth interpretation of quantum mechanics for a free particle, the disappearance and reappearance of interference in the 2-slit problem with a detector behind one are treated in detail. A partial interpretation of quantum theory is employed which is simple, emphasizing description, yet adequate for addressing the present problem.

Given that the eigenvalue equation is essential to predict a free particle’s probability of collision, it is argued that there is equal need for a realistic theory to describe its possible motion. Feynman’s point-to-point space-time wave packet is put forth and used as the appropriate description of the field-free motion between collisions.

For a particle in a conventional 2-slit experiment with attempted detection behind one, the disappearance of interference is explained - both when the detection succeeds and when it doesn’t. Also a definite prediction is made, when the inter-slit distance is reduced, of where the first signs of interference should appear on the detection screen.
1. Introduction

The 2-slit experiment, in which a barrier with two slits between a wave's source and a detection screen causes an interference pattern, is central to many of quantum mechanics' puzzles - measurement, apparent electron bi-location, wave collapse and even non-locality. The quantum interference effect has been studied with photons, electrons and heavier particles. With electrons investigations have been done by Jonsson [1], by Lichte [2], and Tonomura et al [3], and with atoms by Chapman et al [4].

In addition to showing the expected interference in the simple 2-slit experiment, the more puzzling result has always been that any attempt to answer the question “which slit did the electron go through” by attempting to detect it behind one or both slits causes the interference to disappear. This disappearance of the interference is a phenomenon which obviously needs understanding.

In a recent book, Penrose [5] looks at all the most popular attempts that are being made to understand this and other quantum puzzles. Although some approaches seem more promising than others, all are still referred to as works-in-progress with a fuller understanding still to be determined.

The present approach for a free electron, or any quantum entity, interprets the time-dependent Schrödinger equation with static potentials as an equation of motion and its wave function as a description of an electron’s possible space-time motion from a starting point to the location of a possible interaction in its forward direction - ending where and when is encountered the interaction. Treating a free particle’s wave function as simply a description of space-time motion is the way in which a solution of Newton’s equation, and also the wave function \( \Psi \) in quantum field theory (n=0), are understood.

We look for a space-time solution, not of the eigenvalue equation (Eq. 1 below) but of the time-dependent equation (Eq. 2) with one or more static potentials \( V(r_i) \), in the electron’s forward direction - a solution which may consist of one or more wave packets each ending at the site of a potential collision. These wave packet solutions are applied to the 2-slit problem with an attempted detection behind one of the slits - in order to find an explanation for both the absence of interference and its reappearance when the inter-slit distance is made sufficiently small.

The approach has much in common with the probabilistic interpretations of the Schrödinger wave function in that the wave is not treated as a real
physical entity but as a description of possible motion, and also in that the motion is related to a possible interaction - which is a precondition of knowledge. In focusing on a possible localized interaction it is closest to Keller’s [6] probabilistic proof of collapse, and has something in common with that of Ghirardi et al [7] in which a wave may be collapsed by the environment. But the collapse in Keller’s and the present approach is simpler - needing only a single interaction in its environment.

Because it focuses on a free particle with multiple potential interactions \( V(r) \) in its path it is analogous to many histories theories [8,9,10]. Its future histories are also superpositons but ones which describe a possible space-time motion toward each of the competing potential interactions.

The approach has even more in common with that of Zurek [11], but with his environment for a free electron identified with one interaction among a number of possibilities.

It also resembles the deBroglie-Bohn theory of electron motion [12] which likewise emphasizes motion along definite paths. However their individual paths are single classical paths, rather than Feynman’s broad quantum superpositions of such paths.

Finally the approach owes most to Feynman [13]. The point-to-point wave packets we recommend to describe space-time motion for a free particle and to explain the disappearance of interference were shown by him to be solutions of the time-dependent Schrodinger equation, but solutions whose description of particle motion between collisions is very different from the unrealistic plane plus outgoing wave description in the eigenstate solutions of standard quantum theory.

2. Setup for the electron 2-slit problem
2.1 The experiment and its geometry

It is assumed here that an electron is emitted from a source S and ultimately detected at a fluorescent screen D which is distant from the source by at least several centimeters (10⁹ atomic units). Between S and D is a barrier with 2-slits, A on the left and B on the right, which are separated by a lesser macroscopic distance \( d \). In the most interesting versions of the experiment, something to monitor or detect the electron’s presence is inserted just behind a slit (assumed to be slit B here). Since experiments have shown that the interference disappears whether or not the attempted detection has succeeded, the present objective is to analyze what is happening in either case.

2.2 The detection method
It is assumed that the attempt to detect which slit it “went through” is done in a manner which was described by Feynman [14]. He suggested that we try to see the electron by aiming a beam of photons at an area immediately behind one of the slits (slit B). The desired result is to bounce a real photon off the wave, transferring energy and momentum to the electron wave (a Compton effect), and thereby try to verify that it went through B. It is further assumed here that the beam is sufficiently dense that it is impossible for the electron to go through B and continue without first being detected.

This introduces a second possible interaction, the detection, to the problem in addition to the necessary detection screen D. (The word “detection” will be used here to mean “attempted detection” whether or not an interaction with a photon actually succeeds and regardless of whether or not it is directly monitored (by looking for deflection of a photon).

3. The Schrodinger equation with static potential
3.1 The eigenvalue equation

Schrodinger theory is a generalization of Newton’s equation of motion. Schrodinger postulated his eigenvalue equation

\[
\left[ -\frac{\hbar^2}{2m} \nabla^2 + V(r) \right] \Psi = E \Psi
\]

(1)

to predict accurately the discrete energy levels of the Hydrogen atom with the potential term \( V(r) \) being the electrostatic potential energy between the electron and a massive positive charge. With the inclusion of electron exchange it makes similar successful predictions for the permanently bound states of all other atoms and molecules. In general it does the same for the harmonic oscillator, and for a particle inside a potential well or permanently confined inside the (sometimes infinitesimal) range of a potential \( V(r) \).

Its purely spatial wave function \( \Psi(r) \) could be considered a fuzzy description of the particle’s presence everywhere inside the range of the potential and is defined independently of the space-time world outside of this range. The theory also allows the appending of an external periodic time factor which does allow an eigenstate to relate to the outside (e.g. in a superposition with other eigenstates or in other ways).

The eigenvalue equation is also used in standard quantum theory for non-eigenstates, i.e. for propagating particles. What it does correctly and adequately is to predict the electron’s collision cross section at the site of
an actual or possible interaction, and hence its probability of occurrence. This means that it is correct inside the generally very limited range of the potential.

What it does not do correctly is to describe the motion of a free electron in space and time outside the potential’s range, from where it starts to its expected destination at the site of the potential. Solutions of Eq. 1 show an electron as a plane wave coming in from anywhere and going out from the potential in all directions at once. But in reality “an electron goes from place to place” [15] while it moves field-free from a starting point toward the location of a finite range potential interaction \( V(r) \). It does not move from anywhere to everywhere.

Another failure of Eq. 1 is that it assumes the electron is always inside the range of the potential \( V(r) \) which is not true for a propagating particle. It doesn’t allow an electron to be free while it is moving outside the range of both the previous interaction left behind and the possible interaction it is moving toward. This overlooks the fact that the interaction’s range is finite and extremely small (\( \sim 10^{-4} \) cm in the present case with visible photon detection, and would be \( 10^{-8} \) cm for atomic collisions). This \( 10^{-4} \) cm range is infinitesimal compared with the distances to and from the slits which are many centimeters. So the 2-slit photon is completely free on 99.99% of its motion until it finally ends at the location of the possible collision.

So while the eigenvalue equation is essential for predicting what is possible for a propagating particle (the cross sections), there is need for a more general Schrodinger equation (Eq. 2 below) which allows an electron to be field-free and to move from place to place - and for a solution of that equation (Feynman’s) which can describe this motion realistically.

3.2. The time-dependent equation of motion for a free propagating electron

The full time-dependent Schrodinger equation is

\[
\frac{\partial \Psi}{\partial t} = \left( -\frac{i}{\hbar} \right) \left[ -\frac{\hbar^2}{2m} \nabla^2 + V(r) \right] \Psi(r, t)
\]

where \( V(r) \) is a potential interaction of finite, generally very short range in a free electron’s forward direction.

In the present 2-slit problem with a detector behind one slit or in the atmosphere or in gas dynamics studies (where an electron has possible interactions with as many as \( 10^{20} \) atoms [16]), a free point electron or other
particle generally confronts more than one possible interaction. For that reason the $V(r)$ in Eq. 2 should more properly be written as a superposition

$$V(r) = \sum_i V(r_i)$$

(3)

An important advantage of Eq. 2 over the eigenvalue equation is that it allows intrinsically space-time-dependent solutions [13] rather than purely spatial waves with an external time factor. Also its solutions may go directly from one place to another as do real particles.

3.3 The Feynman wave packet solution of the time-dependent equation

Feynman defined a spacetime wave packet, over the range where $V(r)$ is essentially zero, as a superposition of free spacetime paths with each having its own proper time. (In other words both position and time are somewhat uncertain, something detailed further in Sec. 3.4.) From its starting point, the wave packet’s description of the particle’s motion spreads out symmetrically around the vector $r_i$ and then converges to and terminates at the local site of a possible interaction [at a $V(r)$]. He showed that this construction solved the time dependent Eq. 2 from start to end point at the $V(r)$, even though its initial and final boundary conditions make it incompatible with Eq. 1.

Unlike the corresponding unrealistic solutions of the eigenvalue equation, the wave packet’s intrinsically timedependent solution does not extend past the site of the finite range potential $V(r_i)$ to where the particle would be in a different energy/momentum state of motion and where the outgoing spherical wave solution of Eq. 1 describes unphysical motion.

For the simplest collision problems there is only one potential interaction and the solution of Eq. 2 is a single wave packet terminating at that site. For the 2-slit problem with attempted detection at both slits, the solution of Eq. 2 would also be a relatively simple superposition of the two wave packets terminating at A and B respectively. The present paper concentrates on the slightly more complicated case of an attempted detection at only one slit (B).

3.4. Space and time uncertainties for the Feynman wave packet solution

This subsection explores two interesting properties of a point-to point wave packet solution of Eq. 2 (as opposed to a general solution of the Schrodinger equation), deriving them by using the uncertainty principle. Although the uncertainty principle gives only an upper bound it has been shown
that, for waves whose frequency or wave-number distribution is smooth and
even roughly approximates Gaussian shape as is the present wave packet so-
lution of Eq. 2, the principle is a good approximation. It will be used here
to explore both the wave packet’s space and time uncertainties.

Consider a free wave packet propagating forward over a macroscopic dis-
tance D in the laboratory from one local position to another, and with an
average momentum p whose wavelength is much less than D. From the de-
viations from a perfect wave fit between its start and end points one finds
approximately that the wave packet’s uncertainty or spread in momentum in
its forward direction is

$$\Delta p \approx \frac{\hbar}{D}$$ \hspace{1cm} (4)

From this, the spatial uncertainty in the forward direction is

$$\Delta x = \frac{\hbar}{\Delta p} = D$$ \hspace{1cm} (5)

The wave packet’s uncertainty and its forward extension in space are the
same. In other words its spatial resolution undefined over approximately its
entire length and it could as well be anywhere in that span, however long.

The time uncertainty \(\Delta t\) may also be found, starting from

$$\Delta E \approx p \frac{\Delta p}{m} = \sqrt{\frac{2E}{m}} \Delta p \approx \hbar \frac{v}{D}$$ \hspace{1cm} (6)

where (2) has been used, and v is the corresponding classical velocity. From
this, the time uncertainty is

$$\Delta t \approx \frac{\hbar}{\Delta E} = \frac{D}{v}$$ \hspace{1cm} (7)

This is just the classical time of flight over the entire macroscopic path.
So, for a wave packet, time (as well as distance) is completely unresolvable
and therefore meaningless in the center of mass frame of a free point electron
or other particle. The time uncertainty is analogous to the time independence
of the photon in its own frame of reference, to that of an atom’s timeless
eigenstate, and it, along with Eq. 5, is also at least consistent with the
non-locality of propagating quantum particles detected by Aspect [17] for
photons. It is interesting that a more complete time irrelevance is also found at the quantum gravity scale (see for example Barbour [18]).

4. The wave packets with no attempted detection

4.1 The one slit wave - $\Psi_{SAD}$

Although the present paper is concerned only with the 2-slit problem, and there only with attempted detection (Section 5 ff), the purpose of this section is to introduce the appropriate Feynman wave packets in the context of an experiment with slits, - starting with one slit.

If there is only one open slit A, the wave for possible electron motion extends from the source S through slit A and, after deflection, continues to the screen D. Even for this simple example, the potentials $V(r)$ must include first the turning point at slit A and, from A, all of all the potential interaction points on the detection screen, presumably with individual molecules. It may be written as

$$V_{SAD} = V(r_{SA}) + \sum V(R_{ADI})$$  \hspace{1cm} (8)

where the plus sign (+) here is meant to signify “followed by”, and with the $r_{ADI}$ being the vector distances from A to the all the active points on the screen.

For these potentials the solution of Eq. 2 for electron motion is a wave packet from S to A followed by a superposition of minor wave packets from A to the screen D, i.e.

$$\Psi_{SAD} = \Psi_{SA} + \sum \Psi_{ADI}$$  \hspace{1cm} (9)

where the plus sign again means “followed by”. $\Psi_{SA}$ is the wave packet from S to A, and the $\Psi_{ADI}$ are all those with paths going from A to the screen. $\Psi_{SAD}$ is illustrated in Fig. 1 with several wave packets to the screen and a few Feynman paths illustrated for each packet.

4.2 The 2-slit wave (with no attempted detection)

This is the standard 2-slit problem. With a second slit B, there is added a second set of potentials $V(r_{BD})$ for a possible passage of the electron through B. With 2 partially different sets of possible interactions (A and B) for an electron starting at the source S, the 2 possibilities allow a superposition of $\Psi_{SAD}$ with its mirror image $\Psi_{SBD}$ going from S to the same points on the screen through slit B.
Behind the slits the wave packets through, B with their paths, must cross (not shown) and therefore interfere with those through A on their way to the same targets on the detection screen D - as always observed. (They may cross because the non-crossing rule used in Ref. 12 for trajectories applies only to the purely spatial paths in eigenstates and was not proved for space-time paths.)

The philosophical question “which slit?” for this case is outside the scope of the present investigation and is not considered here.

5. The 2-slit problem with attempted detection behind slit B - no interference - $\Psi_{SD}$

When a detector is put behind B, this changes the situation. Before a detection was attempted, all wave packets for possible motion would have crossed and, after going through A and B, terminated at the screen. But with a detector behind B the situation is different. The leftmost branch $\Psi_{SAD}$ through slit A is unchanged. But the wave packet $\Psi_{SD}$ which would have gone from S through B and crossed the paths from A now faces a possible interaction $V(r_{SB})$ whose small range is of order $\lambda$ at that site. The B wave packet therefore terminates at that location by the packet’s point-to-point definition, as pointed out in Section 3.3. This effectively truncates all of its previous paths through B at the limits of this relatively mesoscopically small region.

The overall wave function from the source, with a detector, is therefore the super-position

$$\Psi_{SD} = \Psi_{SAD} + \Psi_{SB}$$ (10)

The plus sign (+) here is meant to signify a superposition of the 2 wave packets. This wave is illustrated in Fig. 2 assuming that the inter-slit distance $d$ is much larger than the range of the potential interaction $V(r_{SB})$ at B where $\Psi_{SB}$ terminates.

[If $d$ is not much smaller than the potential’s range however, the truncation leaves some paths still inside its interaction range of $V(r_{SB})$ at B. This situation is illustrated in Fig. 3 and is pursued further in Section 7.]

With the two major waves in (10) terminating at different locations, the A packets at the screen D while the B packet terminates at the detection region behind B, the question is not “which slit did the electron go through?” but rather “which interaction, that at B or that at D, occurred first?” But either way, whether the attempted detection at B is successful or not, there are no
interfering Feynman paths between the barrier and the screen - and so no possibility of interference - just has always been observed.

5.1 If the electron is not detected behind slit B (null measurement case)

This case is a simple application of the last paragraph. If nothing is detected at B it means that the interaction has been at the screen with one of the minor wave packets of $\Psi_{SAD}$ from slit A rather than at B. Motion from S to slit B (described by $\Psi_{SB}$) is no longer possible. With no B paths interfering with motion from A (Fig. 2), there is no possibility of interference in this case as pointed out above.

The case of a successful detection at B is considered in the next section.

6. If the electron is detected behind slit B

If the electron is detected behind B (here by interacting with a photon from the beam), its location is fixed momentarily at that interaction site, whose size is of order of the electron’s wavelength $\lambda$. The motion described by $\Psi_{SAD}$ is no longer a possibility, and the electron is localized momentarily in the interaction region behind B and ready to move on in a new energy-momentum state.

There is nothing mysterious about the location of a particle when it actually interacts. It has arrived, and is located, at the place where it interacted. This situation looks very much like what is generally ascribed to a mysterious “wave function collapse”. Although an actual interaction and collapse are outside the limited range of the wave function describing motion of a free particle, interactions do happen in the laboratory (and in both classical and quantum field theory) and can’t be ignored. The following subsection reviews some existing evidence showing that collapse of a wave function for particle motion occurs at any interaction which may result, directly or indirectly in detection or in human knowledge.

6.1 Collapse

Indications of wave function collapse have been seen since the earliest days of quantum theory - for photons, electrons and heavier particles. The following are a few relatively recent works tending to confirm its reality.

Ghirardi et al. [7] have used an assumption of random collapses of a real wave to successfully demystify certain quantum paradoxes. (In the present interpretation collapse is associated with any detection interaction.)

A recent paper by Keller [6] demonstrated rigorously for a propagating particle that its wave function, as an amplitude for location in space, is collapsed by any detection. Using conditional probability theory, he proved
that the probability amplitude wave for the location of the ongoing quantum particle immediately following the observation becomes limited to the observation area, in other words its effective size is collapsed to that of the observation area.

Gas dynamic studies have for many decades successfully predicted the behavior of the entities involved by means of classical models. These models treat the entities as particles moving straight from one momentum/energy-transfer collision to another, and another. In retrospect, now that we know the particles move quantum-mechanically, the success of these models shows that the quantum waves for the motion of these gas entities (atoms or whatever) are located (localized, collapsed) at the site of each collision or interaction. An example of one such analysis is that done by Einstein [19].

Many more recent studies of electron mobilities and diffusion in atomic gases by a number of investigators such as Pack an Phelps [20], Huxley and Crompton [21] have included in their calculations and predictions, the fact that an electron’s motion is described by quantum mechanics. In the Boltzmann models, they replaced the atom’s classical cross section with its quantum momentum-transfer cross section as seen by the electron. With this model and accurately calculated cross sections they predicted mobility and diffusion precisely, while continuing to treat the electron as propagating on a vector path from one collision to the next, in other words as behaving like a collapsed particle at every energy/momentum transfer.

A very recent paper by Borghesani and O’Malley [16] found new and more detailed evidence consistent with collapse from electron mobility experiments in Neon. Its density and temperature dependence showed that, even immediately before each collision, the wave packet for electron motion locates the potential interactions within the microscopic area of the electron’s wavelength $\lambda^2$.

In the present interpretation “collapse” means simply that a propagating electron or other quantum particle is present momentarily where and when it collides - something which it seems difficult to dispute.

6.2 After the interaction and collapse - $\Psi_{BD}$

After the collapse then, with the electron localized (collapsed) at the interaction region behind slit B and ready to move on in a new different energy-momentum state, its only possible interactions are the $V(r_{BDi})$ at active points on the detection screen D. Its total potential, as in Section 4.1, may be written as a superposition of potential interactions at all active points on the screen.
\[ V_{BD} = \sum_i V(r_{BDi}) \] (11)

The corresponding wave packet solution \( \Psi_{BD} \) of Eq. 2 for electron motion in this multiple potential (essentially the mirror image of that from A to D in Section 4.1 and Fig. 1) must be a superposition of all minor wave packets from B to each of the \( V(r_{BDi}) \) at D, and may be written as

\[ \Psi_{BD} = \sum_i \Psi_{BDi} \] (12)

Again, as in Section 5, there are no competing paths from the other slit to the screen for it to interfere with and therefore no interference.

The upshot from Sections 5 and 6 is that the presence of a possible detection interaction behind one slit eliminates all interference (assuming very large slit separation d) - both when the interaction at the slit succeeds and when it doesn’t. Its return when d is reduced is explored in the next section.

7. Reducing the inter-slit distance d from infinity toward \( \lambda \)

In order for a detecting photon to distinguish sharply between A and B, the A-B inter-slit distance d should be much larger than the photon’s resolving power (of the order of its wavelength \( \lambda \)). Such a value \( \lambda \) for the distance separating interference from non-interference was confirmed recently by Chapman et al [4] using Sodium atoms and a somewhat different geometry and procedure. They found that, as the distance d is getting close to \( \lambda \), the interference tends to return.

If we start with a very large d for which no interference is visible, as d is decreased and its size begins to approach that of \( \lambda \) from a distance, there are paths (shown inside the circle in Fig. 3) which the truncation at B does not eliminate because they are inside the range of the potential \( V(r_{SB}) \). Fig 3 represents this situation immediately after the detector has been inserted and before an actual interaction occurs, whether it is at B or at the screen. With decreasing d these B paths begin to cross the nearest paths of possible motion from A to the screen, as shown in the figure. The first sign of interference caused by these crossings should begin to be visible - with the details depending on whether the detection behind D was successful or not.

[Note that Fig. 3, as compared with Fig. 2, has been drawn with a constant d and the size of the potential interaction at B greatly exaggerated - because it is only the ratio \( d/\lambda \) which matters. Also for all the figures it
should be noted that were not found by solving Eq. 2 directly. Because the
Feynman wave packets always consist of a straight line vector to the destination
surrounded by symmetric curved space-time paths, no new calculation is needed. Only a few packets to active points on the screen are shown schematically for illustration with a very small number of surrounding paths for each.]

Crossing paths means that amplitudes are added. A crossed wave path
going to the screen, after oscillating as it propagates, should result in either
brighter or dimmer points at the screen, i.e. in part of an interference pattern.
Interference should be seen whether the interaction fails and the A paths go
on to interact at the screen, or if it succeeds at B and it is the subsequent B
paths which ultimately do so.

In the next 2 subsections we investigate what is predicted to be seen
in each case when d is decreased in this way and interference first becomes
noticeable.

7.1 In the null measurement case (no interaction behind B)
The electron, as in Section 5, is confronted in its motion from the source
S with possible interactions either at B or at the screen as shown in Fig. 3.
If it does not interact at B this means that it does so through its major wave
$\Psi_{SAD}$ with paths coming from A. As the figure shows, it is the rightmost
paths from A which must first cross the truncated paths at B. So these
crossing paths from A will be the first to carry some interference to the far
right side of the screen in the figure.

If $d/\lambda$ is decreased further, additional A paths will be crossed by more B
paths and proceed to the screen with the interference they carry spreading
toward the center with larger d, and also becoming stronger because of the
additional B paths crossed.

7.2 When the electron does interact behind B
The initial state of the wave function before the interaction is again that
shown in Fig. 3 with short B paths toward the screen truncated inside and
beginning to cross some B paths also trapped inside the B interaction region.
Interaction initially is only a possibility.

An actual interaction at B localizes the electron there (inside the circle)
and eliminates the possibility of motion through A whose possible motion
was described by the corresponding wave packets from A to the screen.

Starting from the electron wave now collapsed inside of the circle as an
initial condition, with the amplitudes of some of its paths modified by in-
terference from A paths and facing the new possibility of interactions at the potentials \( V(r_{BD_i}) \), the post-interaction wave solution \( \Psi_{BD} \) of Eq. 2 is illustrated in Fig. 4. It must be a superposition of all the minor wave packets proceeding from the B interaction region to the screen. For the electron, one of these packets must actually succeed in reaching the screen and interacting there with its amplitudes possibly modified.

As shown in the preceding subsection and seen if Figs. 3 & 4, the first B paths carrying interference are those pointing toward the center of the screen. As \( d \) decreases further more and more A paths are trapped inside the circle and spread the interference to b paths in both directions but more rapidly to the left than to the right. Also the number of A paths crossed and therefore the intensity of the interference increases rapidly with decreasing \( d \).

7.3 The overall experimental result predicted for reduced inter-slit distance \( d \)

It is assumed here that the simplest experiment is done, with no attempt at monitoring deflected photons, but by directly observing only the earliest emergence of interference patterns on the screen as the inter-slit distance \( d \) is decreased. In this case the predicted interference should begin as a weighted sum of the two effects described above in Sections 7.1 and 7.2.

With decreasing \( d \) (larger circle), the predicted interference on the screen should spread out and also become stronger. In the failed detection case the interference is predicted to spread out from the far right end of the screen (nearest to the detector). With a successful detection at B the interference is predicted to spread from the center of the screen and more rapidly to the left (away from the detector) than to the right with decreasing \( d \).

One additional thing which such an experiment might show is the relative frequency of successful to unsuccessful detections for a particular attempted detection method.

8. Summary

The electron 2-slit problem with the standard geometry and an attempt at detecting the electron behind one has been considered with the time-dependent Schrödinger equation for a free particle understood as an equation of motion, and with its wave function solution interpreted as a mathematical description of its possible or actual motion. The possible motion for this problem is described by a superposition of Feynman’s point-to-point space-time wave packet solutions of the equation with each wave packet related to a particular potential interaction \( V(r_i) \) confronting the electron.
A surprising property of these wave packets was found in the process. They apparently have the property that both time and distance are totally unresolvable in the free particle’s own center of mass reference frame.

The present approach was found to explain the disappearance of interference, both for successful and for unsuccessful photon-mediated detection behind one slit. The case in which the inter-slit distance is gradually reduced from very large was also treated in detail, and definite new predictions were made of where the returning interference would first appear on the detection screen if only the screen is monitored - both when detection behind the slit is successful and when it isn’t.

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Fig. 1. For the 1 slit problem, the figure depicts the solution of the time-dependent Schrödinger equation (1) for possible electron motion from source S to detection screen D. Each wave packet going to or coming from the slit A is a bundle of Feynman paths from start to destination.

Fig. 2. For the 2-slit problem with an attempted detection behind slit B, the figure represents the solution of Eq. 2 when the interslit distance d is very large. The major wave through B finds its termination there because of the potential detection interaction at that point.

Fig. 3. The same as Fig. 1 but with the reduced inter-slit distance d beginning to approach the size of the interaction region. It shows the beginning of crossing (interfering) Feynman paths.

Fig. 4. The wave \( \Psi_{BD} \) with reduced d after a photon interaction at B. With the electron starting anew from B, motion along the paths of the major wave \( \Psi_{SAD} \) through A is no longer possible. The closeness of the slits has also fixed the beginnings of some interfering paths from A inside the interaction site. The only remaining sites of potential interactions are at the screen as shown.

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