Unlocking the Mystery of Interference Patterns in Electron and Photon Double-Slit Experiments and the puzzle of 'Waves without Medium'

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Abstract

The formidable problem with double-slit experiments (and with Quantum Mechanics as a whole) is: if electrons and photons exhibit wave properties (seen as interference patterns), then *what* is waving? What is the medium for transmission of 'electron waves'? Does it give sense at all to talk about 'interference' of a particle? The hypothesis of existence of a medium (the ether) was already disproved experimentally by the Michelson-Morley experiment, in the case of the photon (light). For the electron, such a medium is not even conceivable. Despite the success of Schrodinger's wave function in predicting and explaining the results of experiments, what physical quantity the wave function actually represents is still unknown. Erwin Schrodinger was on the right track with his view of the electron as a 'smeared' object, rather than as a point particle, and with his rejection of the Copenhagen interpretation. Yet he was still far from the ultimate mystery. Then how is a wave possible without a medium? How can a wave property and a particle property co-exist in a single physical entity (the electron and the photon)? Nature uses a simple and subtle trick : the electron *mass density* at a given point of space is directly proportional to the intensity of oscillation of the electron (the electron wave) at that point. The instantaneous mass density of the electron at a given point is directly proportional to the instantaneous vibrational velocity of the electron at that point. This resolves the central mystery in Quantum Mechanics: electron interference pattern. The photon *energy density* at a given point is directly proportional to the intensity of vibration (oscillation) of the electric and magnetic fields at that point. The new theory provides a hint on the mystery behind Planck's relation: E=h.f. Higher frequency photons have higher energy than lower frequency photons just because higher frequency photons *<u>also</u>* have higher amplitudes of electric and magnetic fields.

Introduction

The behavior of electrons and photons in double-slit experiments has been puzzling scientists for decades. There is no intuitive, logical and complete explanation of the observed interference patterns so far. The formidable problem is: if electrons and photons exhibit wave properties (seen as interference patterns), then *what* is waving? What is the medium for the photon wave? The case of the electron is even more perplexing than that of the photon. Does 'interference' of a particle give any sense at all? For the photon (light), at least scientists in the nineteenth century could conceive of a medium (the ether), even though the ether hypothesis was finally disproved by the Michelson-Morley experiment. (The author invites the reader to read a new explanation [1, 2] of the Michelson-Morley experiment).In the case of the electron, it is not even possible to conceive of a 'medium' for 'electron waves'.

Therefore, the idea of a ‘medium’ was somewhat conceptually feasible but disproved experimentally, in the case of the photon, but not even conceivable for the electron.

Schrodinger’s wave function has succeeded in predicting and explaining the results of experiments. But what physical quantity the wave function actually represents is still unknown. According to the Copenhagen interpretation, which is the mainstream interpretation today, the wave function represents a wave of probability associated with every particle. It is the probability of finding the particle at each point of space and time. So it is probability that is waving. So many people reject this idea outright, on their first exposure. Probability is not a physical quantity. Negative probability has no physical meaning. It is counterintuitive.

Alternative interpretations exist, such as the ‘wave-only’ and ‘pilot-wave’. These are more intuitive, but incomplete. For example, in ‘wave-only’ interpretations, the nature of the wave is unknown. No interpretation exists so far that solves the central puzzle: *what* is waving?

Erwin Schrodinger was on the right track with his view of the electron as a ‘smeared’ object, rather than as a point particle, in interpreting the wave function, and with his rejection of the Copenhagen interpretation. Yet he was still far from the ultimate mystery.

The view of a particle as having a definite size is ‘correct’ only if we are talking about ordinary, daily experiences. One comes to a dead end if one tries to explore the microscopic with such a view. If we continue the quest for the meaning of a particle, breaking it down into atoms, electrons, protons, neutrons, then to quarks, we ultimately reach the level of elementary particles, which can not be broken down further. This is a remarkable progress to satisfy our curiosity. However, it will still not bring an end to our curiosity. Conceptually, can we keep on breaking down the particle for ever? There should be an end: elementary particles. Then why does our intuition still keep asking what elementary particles themselves are?

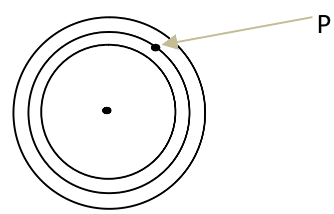
The problem turns out to be our ordinary view of a particle as having a definite size, occupying a definite amount of space.

Such a view ends up in a conceptual discontinuity. Einstein was aware of this problem and was searching for a theory in which a particle is a manifestation of some continuous field. If the electron has a definite diameter, then it will not be possible to represent it mathematically, because there will be a discontinuity at its edge.

As the central mystery of Quantum Mechanics is all contained in the electron or photon double-slit experiment, as Richard Feynman said, we will explore it next.

Discussion

Ordinary waves, such as water and sound waves, are travelling disturbances of their material medium. Consider dropping a stone on a still water, creating circular waves, expanding in every direction with center at the point where the stone was dropped. If we observe what happens at some point P, we see that the water was initially standing still before the arrival of the wave, then a disturbance occurs as the wave arrives, with water molecules oscillating vertically, and the water becomes standing still again after the wave packet has passed.



The water molecules move up and down, vertically, as the wave arrives, because water waves are transverse waves. Although the water molecules oscillate vertically, the molecules are not translating as a whole horizontally with the wave; the water is stationary, is not translating. The same applies to sound and string waves. For sound waves, the air is generally stationary, it is the wave (the disturbance) that is propagating. The air molecules oscillate about their stationary position. The air is not translating as a whole. In all cases, the material media are stationary as a whole.

Here we introduce a subtle and crucial distinction: after the waves have already passed through point P, the water is there, it doesn't disappear. In the case of a particle, however, from our daily experiences, if a particle has already passed through some point of space, we will not find that particle any more at that point.

Now we start modeling the electron step by step, so that we will be able to explain the double-slit interference pattern. At first, consider the electron as a spatially spread object, as an electron field, not as a point particle. Consider it as a sea. Its mass is distributed in space, not concentrated at a very small region of space, with a mass density associated with each point of space. Such a representation should be complete, i.e. it should be possible to represent it mathematically. This requires that there should be no discontinuities. Therefore, theoretically, the electron field should extend to infinity.

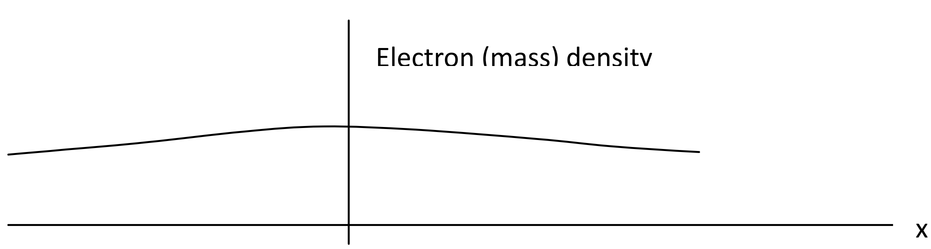


Fig.1

The integration of the mass density of the electron over all of space gives us the known mass of the electron.

The above figure is a one dimensional representation of the electron field. (Note that we are not talking about the familiar electric field of the electron. We are talking particle field). The vertical axis represents mass density of the electron at each point x, instead of probability density of the Copenhagen interpretation. So the electron has been represented here as some kind of fluid, rather than as a rigid classical particle with definite size or as a 'point' particle. As a fluid, just like a body of air or water, therefore, it can transmit waves. Just as for water or sound waves, the electron field, which is the medium for electron waves, is stationary as a whole.

Just as a water wave is a disturbance of water, an electron wave is a disturbance of electron field. The medium for electron waves is the electron (the electron field) itself.

For water waves, the water molecules move up and down independently, in the transverse direction to the velocity of the wave. In a similar way, in the case of electron wave, different 'parts' of the electron can move (oscillate) differently, independently. No 'part' of the electron is rigidly connected with any other 'part'. However, as a particle, all 'parts' of the electron exist as a single entity (the electron). For example, the whole electron (electron field) is emitted and absorbed as a unit. Therefore, each 'part' of the electron can have different, independent motion (oscillation, vibration). Instead of saying 'different 'parts' of the electron oscillate differently', we better say 'the electron can oscillate differently at different points in space'. Just as parts of a sea can have different, independent vertical oscillations, the electron can have different, independent oscillations at different points of space. As water waves are transverse waves, the motion of the molecules is along the vertical direction, in the transverse direction to the velocity of the wave. For the electron wave, let us assume the electron wave to be a longitudinal wave.

But an electron is not a purely wave phenomenon as depicted above. Even though we have visualized it as sea, as a field, it is still an entity (a particle). It is localized in space, it has mass and momentum.

Then how can we incorporate the particle nature of the electron in the above picture?

Consider a water wave packet (a few cycles) described previously. Once the wave packet has already passed through a point in space, the water becomes stand still at that point, just as it was before the arrival of the wave packet. But disappearance of the wave doesn't mean disappearance of the water itself.

The case of the electron wave packet is different. Once the electron (the electron wave packet) has passed through a point in space, the sea (the field) of electron should disappear from that point, because the electron is a particle. From our daily experiences, once a particle has passed through a point in space, it disappears from that point.

Thus, the electron wave packet will be the same thing as the electron itself.

From every day experiences, we know that once a particle has passed through a point of space, the particle will disappear from that point. The sea of the electron should not disappear completely, however, as this will introduce a discontinuity. Once the electron wave packet has already passed through a point, the magnitude of oscillation of the electron and hence the mass density of the electron at that point continuously diminishes towards zero, but should never be zero, for the sake of (conceptual) continuity. Such an assertion might also have further significance.

Therefore, we can have a wave without a medium.

But how is it possible for the electron (the electron field) to disappear once the wave has passed a point? The answer to this question solves the puzzle associated with double-slit experiments.
Here is the trick used by nature:

The mass density of the electron at a given point in space depends on the amplitude of the electron wave at that point. The instantaneous mass density of the electron at any given point depends on the instantaneous velocity of the electron at that point. Note that we are not talking about the familiar translational velocity of a particle, which is the same as the group velocity of the matter wave. We mean the velocity due to oscillation (vibration) of the electron at that point (analogous to the vertical oscillation of water molecules, for a water have). It means that the mass density of the electron is zero at points where the amplitude of oscillation (wave) is zero. This means that there will be no electron at a point where there is no oscillation (vibration). The electron has no representation at that point. The electron can never be detected at that point. Where the amplitude of the electron wave (or oscillation) is zero, there will be no electron. This is unlike a water wave because the water exists independently of the amplitude of the oscillation (or independent of amplitude of the wave) at a point, whether there is oscillation or not.

The mass density of an electron at a point of space is proportional to the vibrational velocity (intensity of vibration) of the electron at that point. This means that the EXISTENCE of the electron at a point in space depends on the vibration intensity of the electron at that point. This resolves the central mystery of quantum mechanics by linking EXISTENCE with intensity of vibration. The more intense the electron vibration at a point in space, the higher the mass density at that point. This will resolve the puzzle of interference in electron double slit experiments. It also resolves the puzzle of ' a wave without a medium'.

The reader may ask: no mention has been made about the familiar translational velocity of the electron (the particle). The translational velocity of the electron is the same as the group velocity of the electron wave.

A complete explanation of the electron wave should also include the phase velocity and the wavelength. The de Broglie wavelength is yet to be explained.

To complete our understanding of the particle nature in the wave picture of the electron depicted so far, we should look at the phenomenon of electron detection.

How is the electron and the photon detected? The following interpretation is made

The electron is *represented* at each point in the electron field. The more the electron mass density at a given point, the more representation the electron has at that point. (The mass density here corresponds to probability density in Copenhagen interpretation).

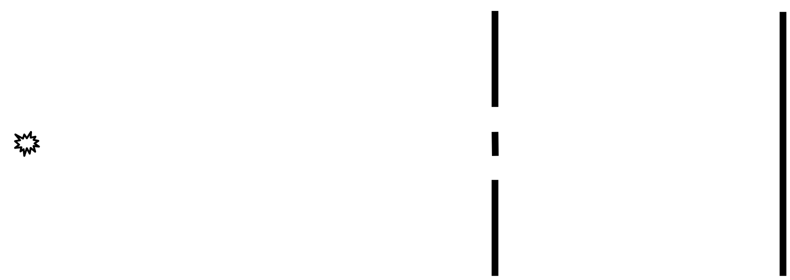


Fig.2

The electron is detected at only one point on the detector screen because the electron, as a single entity, is detected as an entity. The detector detects the electron as a unit, not part of it. At the instant of detection, the mass of the electron that is distributed in the space along the screen will *collapse* to the point of detection. This corresponds to the collapse of the probability wave function in the Copenhagen interpretation. What collapses is the electron mass density wave. The probability that the electron is detected at a certain point on the screen is proportional to the mass density of the electron at that point. The probability here, unlike the probability in the Copenhagen interpretation, is according to the principle of causality and determinism.

The photon

So far we explained the electron wave. Instead of the *mass density* for the electron, *energy density* applies for the photon; otherwise the explanation of the photon wave is the same.

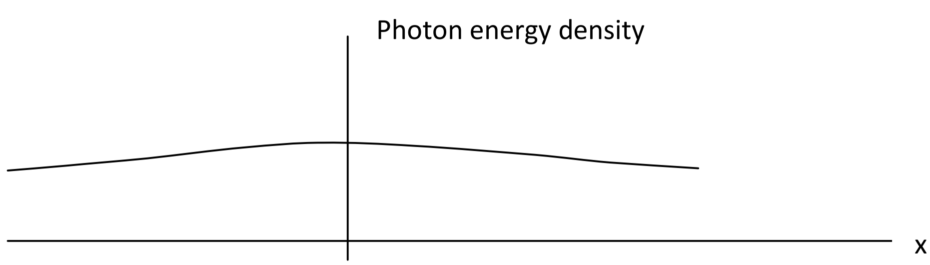


Fig.3

Just as mass is distributed continuously for the electron, the electric and magnetic field is distributed continuously in space for the photon.

Consider again a packet of water waves created by dropping a stone in to a lake. At a point some distance away from the point of disturbance, the water molecules are standing still, before the arrival of the wave. As the wave arrives, the water molecules start to oscillate vertically about their initial position. Once the disturbance has passed away, the water at that point becomes still again.

The disappearance of the wave (the disturbance) doesn't mean the disappearance of the water itself, in the case of water waves. This applies to all ordinary waves such as sound waves and string waves.

The case of the photon is distinct from water waves. We consider the photon as a wave of electric and magnetic fields. Assume a light source emitting photons. Consider a point in space at some distance from the light source. If we take the direct analogy of water waves, the electric and magnetic fields would be 'standing still', i.e. static, not varying, before the arrival of the wave. This means that static electric and magnetic fields would exist at that point even if the photon hadn't arrived yet. As the photon arrives, the electric and magnetic fields would oscillate at that point. Once the photon has already passed away, then the electric and magnetic fields would become static again.

The above direct analogy of a photon with a water wave is erroneous. No varying or static electric and magnetic fields should exist before the arrival of the photon and after the photon has passed through that point. How is this possible?

Nature does this with a subtle trick, in the same way as for the electron wave:

The square of intensity (amplitude) of electric and magnetic fields, i.e. the energy, at any point in space is directly proportional to the rate of change of the electric and magnetic field values at that point.

$$E^2 (x,y,z,t) \;\alpha\; d/dt\, (E(x,y,z,t))$$

Therefore, once the photon wave has already passed through a point of space, there will be no oscillating or static electric and magnetic fields, and hence the intensity of these fields will also diminish continuously towards zero.

This resolves the centuries old puzzle. Light wave does not require a medium of transmission.

Instead of the electric/magnetic field intensity spatial distribution assumed previously (Fig.3), the localized electric and magnetic field intensity distribution is shown below (Fig.4).

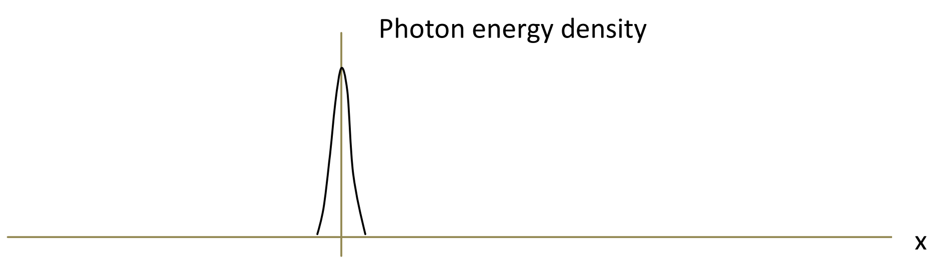


Fig.4

The lower the frequency of oscillation, the lower will be the rate of change of the electric and magnetic field intensities, and hence the lower the intensity (amplitude) of the fields, as discussed so far. The higher the frequency of oscillation, the higher also the intensity of the fields. This may give a hint to the mystery underlying Planck's relation. The square of intensity of electric and magnetic fields(i.e. the energy) is directly proportional to the frequency of oscillation. The constant of proportionality is Planck's constant. Energy = h. f

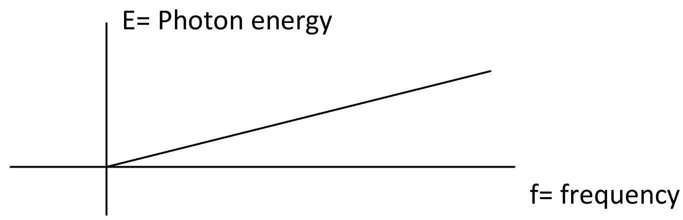


Fig.4

Electron and photon double-slit experiments

Now we can easily explain the observed interference pattern in the double-slit experiment. An electron source emits electrons one at a time from an electron gun. The electron wave front encounters the plate with two slits. The electron wave, as a wave, is capable of passing through both slits. The electron oscillates at every point in space, just like ordinary waves, such as sound or water waves. Assume the electron wave to be longitudinal. The two slits act as two sources and the two electron waves from the two slits interfere at all points in space and along the detector screen. At some points at the detector screen, the waves interfere constructively, hence resulting in higher intensity of longitudinal oscillation of the electron at those points and destructively at some points, resulting in lower intensity of oscillation (vibration) at those points. As we discovered already, the more the intensity of vibration at a given point of space, the higher the mass density of the electron at that point. The higher the electron mass density at a given point, the higher the probability of detection of the electron at that point. The moment the electron is detected at some point on the screen, the mass of the electron that is distributed in space collapses to that point, during the process of detection.

At points on the screen where the waves interfere completely destructively, there will be no oscillation and hence also no electron (zero mass density) at that point. Therefore, the electron will never be detected at that point because the electron has no *representation* at that point.

We can equivalently look at the phenomenon as follows:

As the electron encounters the two slits, it is scattered in different directions after passing through the plate with two slits. The electron is 'broken down' and directed in different directions. The mass of the electron directed in certain directions (regions of constructive interference) is larger than the mass directed in other directions (regions with less constructive interference, or with destructive interference). Even though the electron is broken down into pieces, all the scattered masses still act as a single entity. When the electron is detected at some point on the screen, all the scattered masses collapse to that point.

Conclusion

The two puzzles in quantum mechanics are:

How can an electron (a particle) create an interference pattern, as observed in double-slit experiments? What is the medium for matter waves and the medium for photon waves?

This paper reveals that a single but subtle law of nature underlies all these puzzles:

The electron mass density (and the photon energy density) at a point in space is directly proportional to the intensity of oscillation of the electron wave and the photon wave at that point, respectively.

References

1. http://vixra.org/pdf/1406.0045v5.pdf