Incompleteness of Wave Interpretations of Double Slit and Grating Experiments

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Abstract Young’s double slit experiments, which represent the mystery of quantum mechanics, have been described by wave theories, such as the optical wave theory, the electromagnetic wave (EM wave) theory and pilot wave theory. Recently, the coexistence of the particle nature and the wave distribution of light in double slit and grating experiments has been demonstrated. In this article we utilize the photon chamber to detect the traces of the light beams in the double slit/grating experiments. The existence of the light tracks indicates the particle nature of the light beam in the wave experiments. The particle nature of the light beams is visualized by the tracks, while the wave-like distribution is visualized by the interference/diffraction patterns on screen. Furthermore, we cover the two sides of the photon chamber by metal foils. If the light beams were the EM waves, then the interference/diffraction patterns would be disturbed. The experiments show that the light behave as particles moving through the photon chamber, while distribute as waves without being disturbed. Thus, the double slit/grating + photon chamber experiments visually indicate that the wave interpretations of the optical wave/EM wave theories of the double slit/grating experiments are incomplete, and that the lights are not the EM waves. However, the experiments support the concept of the pilot wave theory at far field. The experiments in this article make the mystery of the double slit experiments even more mysterious, and violate both the wave-particle duality and the complementarity principle.

Keywords: double slit experiment, grating experiment, optical wave theory, electromagnetic wave theory, photon chamber, interference pattern, diffraction pattern, wave-particle duality, complementarity principle


1. Introduction

The evolution of the concept of the nature of light/photons has a long history (Wikipedia). Descartes (1637)/Newton (1704) proposed Corpuscular/particle theory that light is made up of small particles and can explained the reflection and refraction of light. Huygens (1678-1690) proposed the wave theory that explained the phenomena of diffraction and interference. Young (1801) performed the double slit experiment and shown the interference of light, which supports the wave theory. The standard interpretation of Young’s double slit experiment is that the light behaves the same as waves before and after passing through the slide of the double slit. Namely, until strike on a detector, photons behave as waves and interfering. Maxwell (1865) shown theoretically that the electromagnetic (EM) waves move at the same speed of light and thus, predicted that the light is EM waves.

Einstein (1905) explained the photoelectric effect by assuming the light is photons. Then the wave-particle duality emerged. Neither one of two contradictory pictures, wave and particle, can separately explains the phenomena of light fully.

Bohr’s complementarity principle (1927) states that a complete knowledge of phenomena requires a description of both wave and particle properties. It is impossible to observe both the wave and particle aspects simultaneously in the same experiment. “Bohr often spoke of the behavior of quantum objects as beyond ‘visualization’ and thus as being imageless in its literal sense, this behavior is beyond representation of any kind and possibly beyond conception, is unthinkable” [1].

De Broglie (1927)/Bohm (1952) proposed the pilot-wave model [2,3] that explains the wave behaviors as a scattering with wave appearance. “The configuration of a system of particles evolves via a deterministic motion choreographed by the wave function. In particular, when a particle is sent into a two-slit apparatus, the slit through which it passes and its location upon arrival on the photographic plate are completely determined by its initial position and wave function” [4]. Heisenberg (1930) interpreted “the deflection of the trajectory of each diffracted photon as due to […] the spatially regular structure of the diffracting crystal” [5].

The nature of photon puzzled Einstein. He wrote to M. Besso: “All these 50 years of conscious brooding have brought me no nearer to the answer to the question: What are light quanta?” [6].
Feynman (1956) called “[the double slit experiment] contains the only mystery of quantum mechanics” [7].

We argue that one of the reasons why the mystery the double slit experiment is long-standing is the lack of variety of experiments. Recently, the particle nature of light in the double slit and cross-double slit experiments has been confirmed, while the wave-like distributions still exist simultaneously [8,9,10]. However, at the near field, the double slit experiments violate the computer simulation of the pilot wave theory [11,12].

In the particle physics, the cloud chamber [13] and bubble chamber [14], etc., have been invented to detect a particle interacting with the contents by observing the trail. By looking for the track, one can identifies the existence of a particle. A famous example is the finding of positron by Anderson [15].

Following the same concept, we proposed the photon chamber and applied it to the typical wave experiments, such as, the double slit, 1D grating and 2D grating experiments, to exam whether the light beam behave as particles (photons) in those experiments [16,17,18,19]. We observe both the particle nature and the wave-like distribution of light simultaneously in the same experiment. The experimental results are visually observable without ambiguity, which meets the requirement of “visualization” of the behavior of quantum objects.

The photon chamber may be used to study the mystery of the double slit experiments, the nature of light, wave-particle duality and complementarity principle.

According to the Bohr’s complementarity principle, the observation of one phenomenon, say wave distribution, precludes the observation of the other, say the particle nature. Namely, either (1) these two phenomena cannot be observed simultaneously in the same experiment; or (2) if these two phenomena can be observed simultaneously in the same experiment, then the interpretation of the phenomena given by the wave theory is not complete, the Bohr’s complementarity principle is violated, and the standard wave-particle duality is violated.

With the photon chamber, the double slit/grating experiments show the coexistence of the particle nature and the wave distribution of the light in the same experiments simultaneously. A complete theory should be able to interpret the phenomena.

Thus, we suggest that the wave interpretations of double slit/grating experiment as given by the optical wave theory and the EM wave theory are incomplete.

With the photon chamber, “these rather ancient experiments continue to surprise. Something more to ponder” (Ian Miller). “The double slit/grating experiments have much to offer” (Vivien Pinner).

Since the photon chamber can be place along the light beam trajectories, the photon chamber shows the evolution of the interference/diffraction patterns with the distance to the screen.

2. Photon Chamber

For studying the nature of the light in the double slit/grating experiments, we utilize the photon chamber functioning as a photon-detector for visualizing the photons passing through the chamber. The photon chamber (Figure 1) consists of a transparent container filled with the mixture of water and fine powder. Then we apply the photon chamber in the double slit/grating experiments. After passing through the double slit/grating, the light beams enter the photon chamber, in which, the partial of light beam is reflected by the particles of the powder, while the rest light passes through the photon chamber and forms the interference/diffraction pattern on the screen/detector. The tracks of these reflected photons are visible, which indicating that, before landing on the screen/detector, the light behaves as particles, photons.

The purpose of Figure 1b is to test whether the light are the EM waves. The two walls of the chamber are covered by copper foils for shielding the EM wave. If the light were the EM waves, then the interference/diffraction patterns would be disturbed.

The purpose of Figure 1c is to test the computer simulation of the pilot wave theory.

3. Hypothesis

To study the double slit/grating experiments with the photon chamber, we introduced a hypothesis and a definition.

*) Definition: Group of photons.

The group of the photons landing on the same fringe-X is defined as the group-x. For example, the group of the photons forming the fringe m = 0 is defined as the group-0; the group of the photons forming the fringe m = -1 is defined as the group-(-1).

*) Hypothesis: Photons in the same group have the same nature (Figure 2).

We divide the photons passing through the double slit/grating into two parts, the part-1 contains the photons entering the photon chamber, the part-2 contains the photons not entering the photon chamber. The photons of the part-1 face two possibilities, some of the photons are reflected by the liquid in the photons chamber, the rest photons pass through the photon chamber and arriving at the screen.

Hypothesis states that all photons, the part-1 photon and the part-2 photon, have the same nature. The reflected photons and the passing through photons of the part-1 have the same nature.

For example, the photons reflected by the liquid in the photon chamber and the rest photons passing through the photon chamber and forming the interference-fringes/diffraction-orders on the screen, have the same nature. Namely, since the reflected photons showing the particle nature, thus the rest photons of the part-1 landing on the screen and forming the fringes/orders have the same particle nature.
Figure 1. Photon chambers

Figure 2. Schematic of Double slit experiment with photon chamber

Figure 3. Experiment setups
4. Double Slit + Photon Chamber Experiments: Light Behaves as Particles and Distributes as Waves Simultaneously

4.1. Experiment Testing Optical Wave Interpretation of Double Slit Experiment

Experimental setups (Figure 3): (1) The photon chamber-0 and the photon chamber are placed between the laser and the double slit and between the double slit and the screen respectively (Figure 3a); (2) placing the double slit inside the photon chamber (Figure 3b).

The track of the laser light beam in the photon chamber-0 indicates that the light beam behaves as particle, photons. Namely before passing through the double slit, the light behaves as particle, which is consistent with the previous experiments [8,9].

*) Experiment-1 (Figure 4): the experimental setup is shown in Figure 2.

![Figure 4. Double slit experiment with vertical slits: Coexistence of particle nature and wave distribution simultaneously](image)

Utilizing the double slit with vertical slits and the photon chamber-a (as shown in Figure 1a). Placing the photon chamber-a near the screen. The photon chamber-a may be placed at any point between the double slit and the screen. When placing the photon chamber-a near the screen, the tracks of photons are separated clearly. Figure 4a shows the interference pattern without the photon chamber-a.

Observation (Figure 4b): the horizontal photon tracks are observed in the photon chamber-a. Each track corresponds a dimmed fringe, which indicates that the photons have particle nature, while the photons passing through the photon chamber-a form the partial of the interference pattern. The fringes formed by the photons that do not enter the photon chamber-a are not disturbed.

It is difficult for the wave theory to completely explain this phenomenon. The double slit experiment violates the optical wave interpretation.

*) Experiment-2 (Figure 5). We utilize the double slit with the horizontal slits and the photon chamber-a. The experimental setup is shown in Figure 2 and Figure 3.

![Figure 5. Double slit experiment with horizontal slits: Coexistence of particle nature and wave distribution simultaneously](image)

Observation: (Figure 5b): the vertical photon tracks are observed in the photon chamber-a. Each track corresponds a dimmed fringe, which indicates that the photons have particle nature, while the photons passing through the photon chamber-a form the partial of the interference pattern. The fringes formed by the photons that do not enter the photon chamber-a are not disturbed.

It is difficult for the wave theory to completely explain this phenomenon. Namely the wave interpretation of the double slit is incomplete.

*) Experiment-3 (Figure 6): We utilize the double slit with the tilt slits and the photon chamber-a.

Observation: Figure 6a shows the interference pattern without the photon chamber-a in place.

Figure 6b shows: (1) the tilt photon tracks in the photon chamber; (2) the interference pattern on the screen.

*) Experiment-4 (Figure 7): Three compartments of photon chamber are filled with liquid.

Observation: Figure 7a shows the interference pattern without the photon chamber-a in place.

Figure 7b shows: (1) the photon tracks in the three compartments of the photon chamber; (2) the interference pattern on the screen.

Discussion on Experiment-1, -2, -3 and -4: the tracks of photons indicate that the light beams between the double slit and the screen are particles, photons. The hypothesis is confirmed.

On the other hand, the light beams form the interference pattern on the screen simultaneously, namely, light beams distribute as waves.

We suggest that, after passing through a double slit, the photons behaving as particles and distributing as waves simultaneously. It is difficult for the wave theory to completely explain this phenomenon.

This conclusion violates the wave particle duality and Bohr’s complementarity principle.
The conclusion of this phenomenon consistent with previous experiments (see Appendix A1).

3.2. Experiments Testing EM Wave Interpretation of Double Slit Experiment

To test the EM wave interpretation of the double slit experiments, we use the conductive copper foil to shield the light paths partially. If the light was the EM waves, the copper foil would disturb the final interference pattern.

*) Experiment-5 (Figure 8): placing the photon chamber-c with copper foils (shield) (Figure 1b) near and contacting the screen respectively.

**Experiment setup:** First experiment: placing the photon chamber-c with copper foils about 2 inches away from the screen (Figure 8a). Second experiment: placing the photon chamber-c contacting the screen (Figure 8b).

**Observation:**

Figure 8a shows the photon tracks and interference pattern with the copper shields at 2 inches away from the screen.

Figure 8b shows the photon tracks and interference pattern with the copper shields contacting the screen.

Discussion: the experiments show that the light beams between the double slit and the screen are particles, photons. On the other hand, the light beams form the...
interference pattern, namely, light beams distribute as waves. We may say that, after passing through a double slit, the photons, as particles, distribute as waves.

The copper foils (shield/conductive shields) have no effect on the interference pattern. The phenomena confirm the hypothesis.

The copper foils, functioning as shield, do not disturb the interference pattern, thus the light are not waves in the double slit experiments.

The copper foils, functioning as conductive shields, do not disturb the interference pattern, thus the light are not EM waves in the double slit experiments, even light and EM waves have the same speed.

It is difficult for the EM wave theory to completely explain this phenomenon. Namely the EM wave interpretation of the double slit is incomplete.

The conclusion of this phenomenon consistent with previous experiments [10] (see Appendix A2).

4.3. Experiment Testing Pilot Wave Interpretation of Double Slit Experiments

dé Broglie and Bohm theory [2,20,21] states that photons propagate along trajectories. One prediction of the computer simulations of de Broglie-Bohm theory is that the possible trajectories for particles (Figure 9a, extracted from reference [22,23,24]) and for photons (Figure 9b, extracted from reference [25]) cannot cross. We notice an implicit prediction [11,12,26] that there is a triangle-shaped area behind the double slit, in which there is no trajectory (Figure 9), namely, no particle/photons pass through this area (hereafter referred both as "predictions").

*) Experiment-6 (Figure 10). To indirectly test the pilot wave theory, one can test whether there is light in the triangle area.

**Experiment Setup:** placing the double slit in the photon chamber-c against one wall as shown in Figure 1c and 2b. Once passing through the double slit, the light immediately immerses into the liquid. According to the computer simulation of the pilot wave theory, there should be no light immediately next to the double slit.

**Observation** (Figure 10): there are light in the area immediately next to the double slit.

![Figure 9. Computer simulation of pilot wave theory](image)

![Figure 10. Double slit experiment: Double slit in Photon chamber](image)

**Figure 9.** Computer simulation of pilot wave theory

**Figure 10.** Double slit experiment: Double slit in Photon chamber

**Discussion:** Experiment violates the computer simulation of the pilot wave interpretation of double slit experiments. It is difficult for the pilot wave theory to completely explain this phenomenon.

The experiment agrees with the result of previous experiments (for detail please see Appendix A3).

4.4. Discussion

In this Section we utilize the photon chambers to detect the traces of the light beam in the double slit experiments, namely to visualize the passage of light beam. The experiments show that the light beam behaves as particles moving through the photon chamber, while still distributes as wave.

According to the wave-particle duality, the light may be described as either a particle or a wave (as an EM wave in all wave experiments). Neither one of two contradictory pictures, wave and particle, can separately explains the phenomena of light fully.

Bohr’s complementarity principle (1927) (the One of the milestones of quantum mechanics) states that a complete knowledge of phenomena requires a description of both wave and particle properties. It is impossible to observe both the wave and particle aspects simultaneously in the same experiment. These are mutually exclusive and complementary aspects of the quantum system.

To describe the observations, we have introduced the definition of the group of the photons and the hypothesis that photons in the same group have the same nature in
Section 3. As an example, considering the group-X of the photons, which includes both the photons reflected by the liquid in the photon chamber and the rest photons passing through the photon chamber and forming the interference fringe \( m = X \) on the screen. Since the reflected photons show the particle nature, thus the rest photons of the same group landing on the screen and forming the fringes have the same particle nature.

In this Section, the photon chamber experiments show that the light behave as particles, while distribute as wave, simultaneously in the same wave interference experiment. The interference patterns are mathematically described by wave theories, but the light behaves as particles simultaneously in the same experiment. The experimental observations violate the wave-particle duality, and violate the Bohr’s complementarity principle.

A complete theory should be able to interpret the phenomena of the coexistence. The optic wave theory and EM wave theory cannot completely explain the above phenomena. Thus, both the optic wave interpretation and the EM wave interpretation of the double slit experiments are incomplete.

The experiments in this Section make the mystery of the double slit experiments even more mysterious. The double slit experiments violate the computer simulation of the pilot wave theory at near field, but support it at far field. It seems that the concept of the pilot wave theory works.

5. 1D Grating + Photon Chamber Experiments: Light Behaves as Particles and Distributes as Waves Simultaneously

5.1. Experiment Testing Standard Wave Interpretation of 1D Grating Experiment

In the 1D and 2D grating experiments, we use the bigger photon chamber with AL foils (Figure 11a).

Experiment-7 (Figure 12 - Figure 15): Grating Producing Horizontal Diffraction Pattern: Light Behaves as Particles.
First we show the horizontal diffraction pattern before placing the Photon chamber (Figure 12).

![Figure 12. Diffraction pattern of transmission grating with vertical slits](image)

Then placing the Photon chamber between the grating and the screen (Figure 11).

We observed the tracks of the light passing through the Photon chamber (Figure 13-Figure 15).

Observation (Figure 12-Figure 15): In Figure 12, the experiment shows the wave distribution without the Photon chamber in place. Figure 13 shows one track of the light beam passing through the Photon chamber. Figure 14 shows four track of the light beam passing through the Photon chamber. Figure 15 shows multi tracks of light beams passing through the Photon chamber.

![Figure 13. One light beam passing through Photon chamber](image)

![Figure 14. Four light beams passing through Photon chamber](image)
The above experiments indicate that the light behaves as particle (shown by the track of light in the Photon chamber), while still distributes as wave (shown by the diffraction pattern).

**Experiment-8** (Figure 16-Figure 19)
Grating Producing Vertical/Curved Diffraction Pattern: Light Behaves as Particles
First, we observed the vertical diffraction pattern before placing the Photon chamber (Figure 16).

Then placing the Photon chamber between the grating and the screen (Figure 11). We observed the tracks of the light passing through the Photon chamber (Figure 17 - Figure 19).

**Observation** (Figure 16-Figure 19): Figure 16 shows the vertical diffraction pattern without the Photon chamber in place. Figure 17 and Figure 18 show Multi vertical tracks of light beams passing through the Photon chamber when we rotate the grating. The curved pattern due to the rotation of the grating is observed [27].

**Experiment-9** (Figure 20)
Grating Producing Tilt/Curved/Inclined Diffraction Pattern: Light Behaves as Particles
For the tilt grating, the diffraction pattern is tilt. Then placing the Photon chamber in the place, and rotating the grating. We observed the curved and inclined pattern (Figure 20).

**Figure 20.** Multi light beams passing through Photon chamber

**Observation (Figure 20):** Multi tracks of light beams passing through the Photon chamber is observed. The pattern is curved and inclined.

### 5.2. Experiments Testing EM Wave Interpretation of 1D Grating Experiments

To test the EM wave interpretation of the double slit experiments, we use the conductive AL foil to shield the light paths partially (Figure 11a). If the light was the EM waves, the copper foil would disturb the final interference pattern.

**Experiment-10 (Figure 21)**

Placing the Photon chamber between the grating and the screen (Figure 111).

**Observation (Figure 211):** We observed the tracks of the light passing through the Photon chamber (Figure 21).

The AL foil has no effect on the tracks of the light beams, and no effect on the diffraction pattern.

**Figure 21.** Two light beams passing through Photon chamber with AL foils covering both sides

#### 5.3. Discussion

In this Section we propose a Photon chamber to detect the traces of the light beam in the 1D grating experiments, namely to visualize the passage of light beam. The experiments show that the light beam behaves as particles moving through the Photon chamber, while still distributes as waves in the photon chamber and on screen.

According to the wave-particle duality, the light may be described as either particles (as photons in photoelectric effect) or waves (as electromagnetic waves in all wave experiments).

Bohr’s complementarity principle (the One of the milestones of quantum mechanics) states that a single quantum can exhibit a particle-like or a wave-like behavior, but never both at the same time. These are mutually exclusive and complementary aspects of the quantum system.

However, the Photon chamber experiments show that light behave as particles, while distribute as waves, simultaneously in the same wave diffraction experiment.

In this Section, we show that: although the 1D-grating diffraction experiments are well described mathematically by wave theories, the light behaves as particles simultaneously in the same wave experiment and thus, violates the wave-particle duality, and violate the Bohr’s complementarity principle.

We suggest that the optical wave interpretation and EM wave interpretation of the 1D grating experiments are incomplete.

**The light is not the EM wave.**

### 6. 2D Grating + Photon Chamber Experiments: Light Behaves as Particles and Distributes as Waves Simultaneously

#### 6.1. Experiment Testing Standard Wave Interpretation of 2D Grating Experiment

**Experiment Setup:** The experiment setup is shown in Figure 11b. Two photon chambers, the photon chamber-0 and the photon chamber, are placed between the laser and the grating and between the grating and the detector/screen respectively.
The track of the laser light beam in Figure 22 indicates that the light beam behaves as particle, photons. Namely before passing through the grating, the light behaves as particle.

**Experiment-11 (Figure 23):** Grating Producing 2D-Diffraction Pattern: Light Behaves as Particles.

Figure 23a shows the diffraction pattern without the photon chamber.

**Observation (Figure 23):**

Figure 23a shows the 2D-diffraction pattern produced by the 2D-grating without the photon chamber. The pattern contains a large number of diffraction orders. It is a typical wave experiment. The light beams pass through the grating and finally land on the screen and form the diffraction pattern.

Figure 23b is the top view, which shows the tracks of the laser beams inside the photon chamber.

Figure 23c is the closer look at an angle. Each diffraction order on the left-side wall of the photon chamber corresponds a diffraction order on the right-side wall, and a light-track connects both orders.

We suggest that this experiment shows the challenge that the light beams pass through the photon chamber from the left-side to the right side behaving as particles, while the light beams distribute as waves on the left-wall and the right-wall of the photon chamber, and finally form the diffraction pattern on the detecting screen.

![Diffraction pattern](image)

Figure 23. Diffraction pattern of 2D grating
**Experiment-12 (Figure 24): tilt Grating Producing 2D-Diffraction Pattern: Light Behaves as Particles**

**Observations:** Figure 24a shows the diffraction pattern of the tilt grating without the photon chamber.

Figure 24b shows the diffraction pattern of the tilt grating CW rotating 30° without a photon chamber. The diffraction pattern is curved and inclined [28].

Figure 24c and Figure 24d show the diffraction patterns of the tilt grating CW rotating 30° within the photon chamber. The pictures are taken from different angles.

**6.2. Examples of 2D-Grating Producing Diffraction Pattern: Light Behaves as Particles**

Next are some examples of the tracks shown in the photon chamber during the 2D-grating experiments.

**Observation (Figure 25):** Tracks of multi light beams passing through the photon chamber is observed.

**6.3. Discussion**

In this Section, we utilize the photon chamber to detect the traces of the light beam in the 2D-grating experiments, namely to visualize the passage of light beam.

The wave-particle duality states that the light may be described either as a particle (as photons in photoelectric effect) or as waves (as an electromagnetic wave in all wave experiments).

Bohr’s complementarity principle (the One of the milestones of quantum mechanics) states that a single quantum can exhibit a particle-like or a wave-like behavior, but never both at the same time. These are mutually exclusive and complementary aspects of the quantum system.
In this Section, we show that: the 2D-grating diffraction experiments are well described mathematically by wave theories, but the light behaves as particles (shown by the photon chamber) simultaneously in the same experiment. Thus, the grating experiment violates both the wave-particle duality and the Bohr’s complementarity principle. The photon chamber experiments suggest:

1) the light may be described as a particle (for example, in the Photon chamber, and the photon chamber may be placed anywhere between the grating and the screen and between the laser source and the grating) and as waves (as distribute on the detecting screen) in the same grating experiment.

2) The challenge is to explain physically the fact that the light beams behave as photons, while still distribute as waves on the screen.

3) The photon chamber shows the evolution of the diffraction pattern with the distance to the screen.

7. Conclusion

The wave patterns of the double slit, 1D grating and 2D-grating experiments are well described mathematically by wave theories, but the light behave as particles (shown by the photon chamber) simultaneously in the same
experiment. The photons move along the trajectories, and the trajectories distribute as the interference/diffraction patterns.

Thus, we suggest:

1) the double slit, 1D grating and 2D-grating experiments violate both the wave-particle duality and the Bohr’s complementarity

2) The light are not the EM waves.

3) The wave interpretations of the double slit, 1D grating and 2D grating experiments are incomplete.

The photon chamber is very inexpensive and easy to be home-made and thus, can be utilized to study the nature/behavior of the light.

With the photon chamber, “these rather ancient experiments continue to surprise. Something more to ponder” (Ian Miller). “The double slit experiments still have much to offer” (Pinner).

We raise a fundamental question: the experiments showing that the photons propagate as particles in the typical wave phenomena, is the speed of the photons a constant?

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References


Appendix

Comparison between Previous Modified Double Slit Experiments and Experiments of this article

Although the previous modified double slit experiments and the modified double slit experiments presented in this article led to the same conclusions, the experimental devices, experimental setups and experimental observations are different as shown below.

A1. Double Slit Experiments with Shields/Blockers Violate Wave Interpretation of Light [8,9,11]

A1-1. Standard Wave Interpretation

![Standard wave interpretation of double slit experiments](abyss.uoregon.edu)

The standard wave interpretation states that the light passing through two slits interfere to each other (Figure A1a) and form the interference pattern (Figure A1b).

If we place shields (Figure A2a) and blockers (Figure A2b) in front of the detector, according to the standard wave interpretation, the existence of shields and blockers will disturb the interference and will affect the interference patterns.

![Shields/Blockers Testing Standard Wave Theory](abyss.uoregon.edu)

A1-2. Double slit experiment violates Standard wave interpretation

*) Experiment-A1: Double slit with shields

Let’s one end of shield-1 touches the detector at the center of zeroth-fringe, while one end of shield-2 touches the detector at the center of first-fringe (Figure A3a).

![Modified double slit experiment violates Standard wave interpretation](abyss.uoregon.edu)
**Observation** (Figure A3b): the interference pattern as a whole has no change.

**Conclusion:** This phenomenon is consistent with the observation of Experiment-5 with copper foil.

*) Experiment-A2: Double slit with blockers

**Observation** (Figure A4b): each fringe is formed independently, i.e., each fringe is formed by the photons moving along the straight-line trajectories. The remaining interference pattern has no change.

**Conclusion:** This phenomenon is consistent with the observation of Experiment-1 and -2.

Before arriving the detector, photons move along pre-determined trajectories that are straight lines.

![Figure A4. Modified double slit experiment violates Standard wave interpretation](image)

The standard wave interpretation cannot explain: (1) why the two shields (could be more) did not disturber the interference pattern (Figure A1); (2) why each blocker only affects the corresponding fringe. Thus, we suggest that the optical wave interpretation is incomplete.

Now let’s test what are the effects of combinations of shields and blockers.

**Experiment-A3: Double slit with Shields and blockers**

Now let us place blocker-1 at the other end of shield-1 and shield-2, where we denote it as Entrance, i.e., photons enter the narrow channel between shield-1 and shield-2 from there (Figure A5a). The interference pattern is formed on blocker-1 instead of the detector (Figure A5b).

![Figure A5. Double slit with shields and blocker](image)

We perform this experiment in two setups.

**Experimental Setup-1** (Figure A6a): Cutting the top portion of blocker-1.
Observation (Figure A6a and A6b): the bottom half of the fringes are still on blocker-1, while the top half are on the detector. Namely fringes can be formed partially. And shields have no effect at all.

Experimental Setup-2 (Figure A7a and Figure A7b): cut a “U” shape gap at the position of the zeroth-order fringe on blocker-3.

![Figure A7. Blocker-3 with Cut](image1)

Observation (Figure A7c): Photons pass through the cut and form the exactly same shape of patterns on the detector, which: (1) shows the particle nature of light; (2) indicates that photons move along straight lines; (3) the pattern is formed partially.

A2. Double Slit + Metal Tube Experiments: Violate EM Wave Interpretation of Light

To test whether the light behave as EM waves, we insert longitudinal conductive metal tube (Figure A8), either near or contacting the detector [10]. The tube’s orientations are from the center of the double slit pointing to the center of the pattern respectively. The distance between the double slit and the detector is 110 inches (2750 mm). The drawings in Figure A8 are not to scale.

We want to observe whether the interference pattern would be disturbed

![Figure A8. Experiment Setup with Metal Tube](image2)

The standard explanation of the double slit experiments is that the light propagates as wave between the slide and the detector (Figure A8). Furthermore, the light is considered as the EM waves. According to the wave theory and EM wave theory, the metal tube should prevent waves from interfering. Namely, if the light would propagate as waves/EM waves, as shown in Figure A9, then the metal tube would disturb the light waves and the interference pattern.

![Figure A9. Double slit experiment with tube](image3)
*) **Experiment-A4: Double slit with metal tube**

To test the EM wave explanation of the double slit experiments, let us place the metal tube near and contacting the detector respectively. The metal tube’s orientation is from the center of the double slit points to the center of the pattern. The dimension of the tube is 16 mm x 24 mm x 1220 mm, and the wall of the tube is 2 mm thick. The distance between the double slit and the detector is 110 inches (2750 mm).

Rotating the slide of the double slit to the angle so that the pattern is curved upwards (Figure A10a) and then, stop the rotating. Inserting the tube between the double slit and detector, and 1 inch (25 mm) from the detector (Figure A10b and Figure A10c).

![Curved pattern](image1)

**Figure A10.** Modified double slit experiment violates EM wave interpretation (1)

**Observation** (Figure A10b and A10c): photons pass through the tube and form four of the fringes on the detector. The four fringes are the same as there was no tube. The two red spots on the two vertical walls at the “entrance” of the tube indicate that the vertical wall block some photons and form projection on the detector. Here the “entrance” stands for the opening of the tube that photons enter the tube. The two projections are next to the four center fringes.

The remaining photons form the rest pattern (Figure A10b) that is the same as there was no tube (Figure A10a). Figure A10d shows that, when the tube is closer to the double slit (say, one inch from the double slit), there is no interference pattern on the detector.

**Conclusion:** the conductive metal tube does not affect the interference pattern except the projections. The observed phenomena would be expected only if photons behave as particles, but not as waves/EM waves.
*) **Experiment-A5** (Figure A11): The metal tube contacting the detector

![Figure A11. Tube with opening](image1)

In order to make the tube contacting the detector and be able to take picture, need to cut an opening on the top of the tube (Figure A11).

![Figure A12. Modified double slit experiment violates EM wave interpretation](image2)

**Observation** (Figure A12): the touching tube has no effect on the curved pattern, except the two vertical edges block some fringes to form two projections.

**Conclusion:** the light in the double slit experiments are not EM waves. Thus we suggest that the EM wave interpretation of the double slit experiments is incomplete. The light is no the EM wave.

### A3. Double Slit Experiments Violate Pilot Wave Interpretation of Light: Near Field

de Broglie-Bohm theory can interpret the double slit experiments well for far field. The light behave as particles and are guided by the pilot waves.

#### A3-1. Pilot Wave Interpretation

de Broglie and Bohm theory states that photons propagate along trajectories. One prediction of computer simulations of de Broglie-Bohm theory is that the possible trajectories for particle and for photons cannot cross [22-25]. We notice an implicit prediction that there is a triangle-shaped area behind the double slit, in which there is no trajectory (Figure A13), namely, no particle/photons pass through this area (hereafter referred both as “predictions”). The modified double slit experiments have been performed to test those two predictions of computer simulations of Bohm trajectory theory in Z-2 [11,26].
A3-2. Experiments Violating Trajectory Theory: Near Field

Experiment-A6 (Figure A14 and Figure A15): Placing the shield contacting the double slit.

Experimental Setup (Figure A14): making a shield (gray colored) and gluing it to an object (Figure A14b). The shield is 2.8 mm long, 9.5 mm wide, and 0.12 mm thick. The drawing is not to scale.

The shield is placed along the virtual centerline and contacts the double slit at the point between two slits (Figure A14c and A14d), where the spacing “d” between two slits is 1 mm.

Then turning on the laser.
**Observation:** the light from the right-side slit shines on the right side of the shield (Figure A15a), while the light from the left-side slit shines on the left side of the shield (Figure A15b). The light spots on both sides of the shields indicate that there are light/photons in the triangle area. The shield is brightest close to the slits. The interference pattern exists (for detail, see [22]), but is dimmer.

We show that the trajectories cross, while the wave distribution exists, which is agree with experiment of this article.

**Conclusion:** in the triangular area, first, there are light/photons; second, trajectories cross. Thus, we suggest that the experimental observations challenge the predictions of computer simulation of the trajectory theory at near field. Thus we suggest that the pilot wave interpretation of double slit experiments is incomplete.

### A-4 Comparison between previous and present modified double slit experiments

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