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Comprehensive Double Slit Experiments Showing that Light Is Photons

Hui Peng
James Peng Lab, Fremont, CA 94536 USA
Email: davidpeng1749@yahoo.com

Abstract

Young's double slit experiments have been descripted by wave theories, i.e., before and after passing through a double slit, the light is waves. To test the wave description, we extend the double slit experiments to the comprehensive double slit experiments which are the classical double slit experiments with added either Shield, or Blocker, or Metal tube, or Combination of Shield and Blocker, or Photon-Chamber, or Lens. We propose both "Postulate on light: light is photons before and after passing through double slit" and "Postulate on lens: light behaves same before and after passing through lens". Then, we show the novel phenomena of the comprehensive double slit experiments: (1) the light is photons, not waves, before and after passing through a double slit; (2) it is the photons that form both the non-interference patterns and interference patterns in the same experiment; (3) the non-interference patterns gradually evolve to the interference patterns in the same experiment. We refer to the novel phenomena as "PhotoWave phenomena" that are universal. The comprehensive double slit experiments provide the novel phenomena for developing theoretical model to study: (1) the nature of the light; (2) the wave theories of the light; (3) the quantum theory of the light. A

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complete explanation is demanded and should describe all the comprehensive double slit experiments consistently.

Keywords: double slit experiment, interference pattern, non-interference pattern, Shield, Blocker, Photon-Chamber, lens, PhotoWave phenomena

1. Introduction

Historically, the study of the nature of the light reached basically two concepts: wave and particle. The double slit interference pattern is one of basic phenomena in the physical optics.

In 1801, Young proposed the hypothesis that the light should behave similar to both water waves and sound waves. In order to test his hypothesis, Young designed/performed the double slit experiment, observed the *interference pattern*, and proposed that the interference pattern could only be produced if the light was waves. The wave explanation of Young's double slit experiment was not immediately accepted by people who believed that the light propagated as particles [1], but they did not proposed/performed experiments to support their theory.

The water waves and the sound waves are *not the physical entities*, instead, they are just the vibrations of the water particles and air particles respectively. Thus, for explaining Young's experiment, a hypothetical medium "Ether" was introduced and believed to carry light waves.

In 1860s, Maxwell predicted the speed of the electromagnetic (EM) waves, which is very close to that of the light. This was considered as evidence for that the light is EM waves.

In 1887, Michelson-Morley experiments were unable to detect the “Ether”. This indicated that the light is not the wave vibrating in a medium. Since then, it is assumed that, unlike the water waves and sound waves, the light does not require a medium to propagate. Without the Ether, *the light propagates* not as the vibrations of the Ether, but *as the real physical entities*.

From 1887 to 1905, H. Hertz, J.J. Thomson, P. Lenard, and A. Einstein discovered and interpreted the “Photoelectric effect”, which shown that the light is photons.

In 1924, de Broglie noticed that the light behaves as both the waves and particles. Then, he extended this dual concept of the light to the matter, and proposed the “de Broglie matter wave” and the wave-particle duality.

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In 1926, the “de Broglie matter wave” led Schrodinger to propose the “Schrodinger wave equation” to describe the matter-wave, the basis equation of the quantum mechanics.

Table 1. Studying nature of light leads to quantum mechanics

Light is Particle 1704 Newton (theory) 1887 Hertz (experiment) 1905 Einstein (theory)	**Electron is particle** 1897 Thomson (experiment)
Light is waves 1690 Huygens (theory) 1801 Young (experiment)	**Electron is wave** 1924 de Broglie matter wave Wave-particle duality
	Quantum mechanics 1926 Schrodinger wave equation

Table 1 briefly summarizes the study of the nature of the light, shows it led to the concept of the matter-wave and further, to the Schrodinger wave equation of the quantum mechanics.

Until 1951, the wave-particle duality of the light still puzzled Einstein, he wrote “All these 50 years of conscious brooding have brought me no nearer to the answer to the question: What are light quanta?” [2].

In 1956, Feynman called the double slit experiment "a phenomenon […] has in it the heart of quantum mechanics. In reality, it contains the only mystery. We cannot make the mystery go away by ‘explaining’ how it works" [3].

In 2013, W. Rueckner and J. Peidle detected single photoelectrons liberated by the light. Then they assumed that a single photon produces the interference pattern in double slit experiment [4]. In 2016, R. S. Aspden, M. J. Padgett, and G. C. Spalding shown the single-photon double-slit interference [5].

In 2021, Peng showed the comprehensive-double-slit experiments [6].

In 2022, R. Penrose in an interview stated: “this is not something that people normally even recognize as a problem I mean they do but they shove it under the carpet which is known as the collapse of the wave function. Now you see current quantum mechanics strictly speaking is an inconsistent theory that is rather brutal way of saying what Einstein and Schrodinger and even Dirac said that quantum mechanics is incomplete” [7].

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We argue that one of the reasons why the mystery of the double slit experiment is long-standing is the lack of the variation of experiments. To study the nature of the light in the double slit experiments, we propose to add either Shield, or Blocker, or Metal tube, or Photon-Chamber, or the convex lens in the experiments, referred to such experiments as the comprehensive double slit experiments. The comprehensive double slit experiments show for the first time the ***PhotoWave phenomena*** (the light is photons and it is photons that form both the non-wave- pattern and the wave-pattern in the same experiment).

If the light was the waves, then the Shield and Blocker would disturb the wave-patterns.

If the light was the EM waves, then the Metal tube would disturb the wave-patterns.

To show the particle nature of the light, we place Photon Chambers between the light source and double slit, and between the double slit and detector.

Utilizing the convex lenses in the double slit experiments, we show the pattern evolution, i.e., the non-interference pattern evolving to the interference pattern, which reveal the fundamental nature of the light.

To interpret consistently the PhotoWave phenomena is a challenge. The PhotoWave phenomena are fundamentally significant in the further development of optics/physics. Our experiments provide new evidences for studying the optics/physics further.

2. Zones and Postulates

2.1. Four Zones

Let us divide the space between the laser source and the screen/detector into four Zones (Figure 1) and define the corresponding patterns in each Zone.

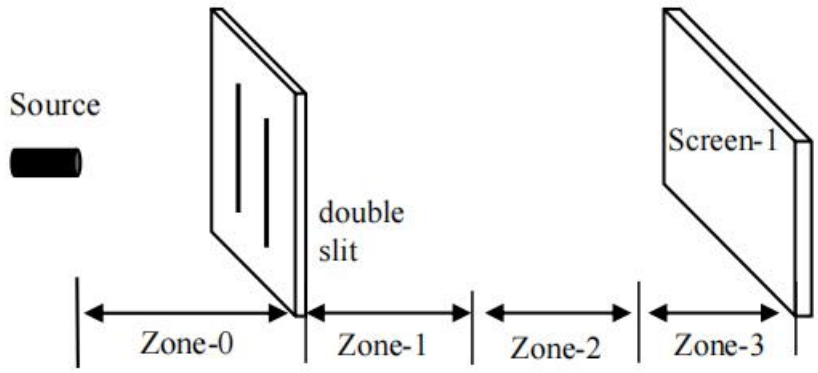

Figure 1. Four Zones

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(1) Zone-0: between the source and the double slit, in which the pattern is non-wave and thus, the light is particles;

(2) Zone-1: near the double slit, in which the patterns are *non-interference* and thus, the light is particles; referred to the patterns as ***Particle patterns***;

(3) Zone-2: between zone-1 and zone-3, in which the patterns are *non-interference* and thus, the light is particles; referred to the patterns as ***Transition patterns***; in Zone-2 Particle patterns in Zone-1 gradually evolve to the Interference patterns in Zone-3.

(4) Zone-3: near the screen, in which the patterns are ***Interference patterns***;

(5) Surface of the screen: on which the light lands as particles and it is the particles that distribute as interference pattern.

2.2. Postulate on Light

"Classical Postulate on light": ***the light is waves before and after passing through a double slit***. To my knowledge, there is no experiment testing it. The existing experiments only show that the light distributes as the interference pattern ***on the detector***, but not between the double slit and detector, i.e., Zone-1, Zone-2 and Zone-3, and not between the light source and double slit, i.e., Zone-0.

Now, we propose a new Postulate on light and experimentally test/confirm it in this article.

"Postulate on light": ***Light is particles before and after passing through a double slit, and landing on a detector.***

One of the conclusions of the "Postulate on light" is that the nature of the Light in a double slit experiment does not change. Namely, if an experiment confirms that the light is particles in one of Zones, then, the light is particles in all of Zones. It is photons that produce the both the non-interference patterns and the interference patterns, we referred to it as the PhotoWave phenomena.

Postulate on light completely alters the understanding of the nature of the light, especially the nature of the light in the double slit experiment.

Example: If the light shows particle nature in Zone-1, then the light is photons in all four Zones, i.e., the light has the same particle nature before and after passing through double slit.

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Note: Postulate on light avoids introducing the concept of the "*Collapse of Wave Functions*" and thus, supporting Penrose's statement [6].

Both the "Classical Postulate on light" and "Postulate on light" state that the double slit does not alter the nature of the light passing through it.

2.3. Postulate on Lens

In Textbooks, the theory of the convex lens is directly applied to the wave experiments of the physical optics. In the classical wave experiments, the diaphragm stays at the same location. The light coming out the slits has the certain pattern. In Textbooks, it was assumed that the function of the convex lens is to *bring light rays to a focal point P on the screen.* This assumption is based on the geometrical optical theory of the lens. But we will show that the pattern changes with the distance from the diaphragm.

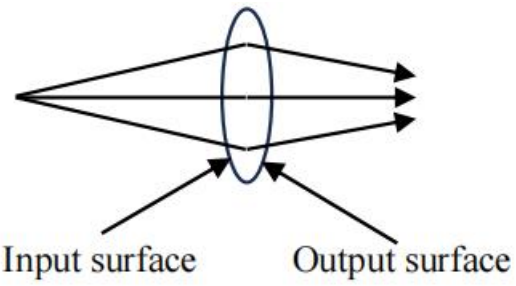

Figure 2. "Input surface" and "Output surface" of convex lens

To study the evolution of the patterns, the convex lens moves and thus, the patterns arriving at the input surface of the convex lens (Figure 2) change. The light patterns arriving at the input surface of the convex lens are position-dependence. Based on above consideration, we suggest the Postulate on lens.

Postulate on lens:

(1) the convex lens enlarges the image that arrives at the input surface;

(2) The convex lens breaks the evolution of the patterns;

(3) The convex lens does not change the behavior of the input pattern.

Example: After passing a convex lens, the patterns keep the same nature: e.g.,

(a) if the input pattern is Particle pattern, the output pattern is still Particle pattern, and vice versa;

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(b) if the input pattern is Transition pattern, the output pattern is still Transition pattern, and vice versa;

(c) if the input pattern is Interference pattern, the output pattern is still Interference pattern, and vice versa.

3. Light is Photons before and after Passing Through Double Slit

3.1. Light Is Photons Before Passing Through Double Slit

3.1.1. Double Slit experiment with Photon Chamber

Now, let us experimentally show that the laser beam is particles before passing through a double slit, i.e., in Zone-0, the light is particles.

Experiment-1 (Figure 3): Light is photons before passing through double slit:

Experimental setup (Figure 3a): Placing a Photon Chamber between the laser and the double slit (Zone-0).

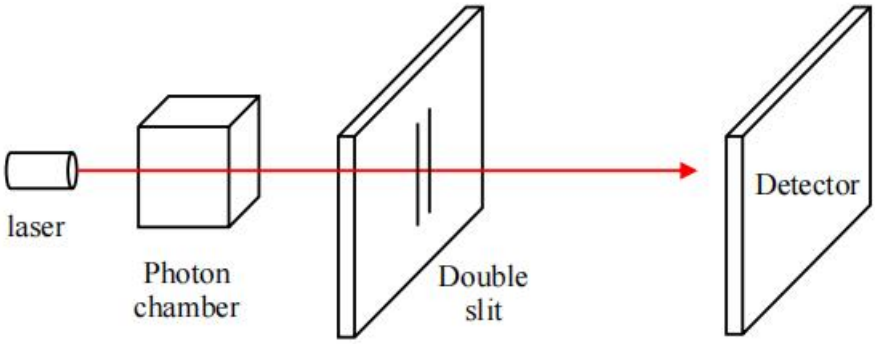

Figure 3a. Experimental setup

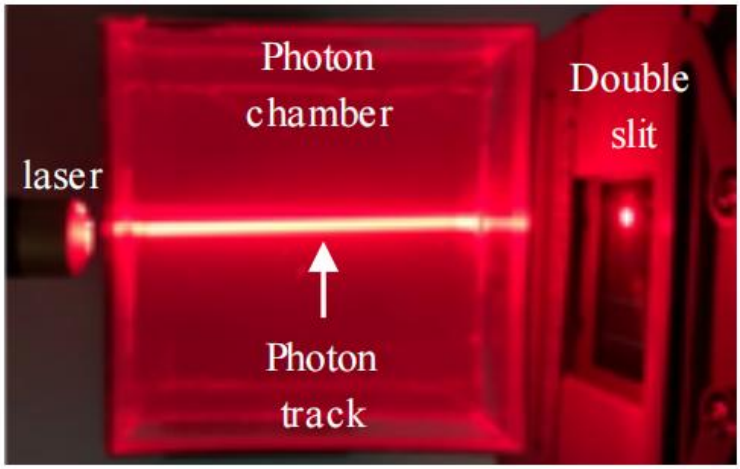

Figure 3b. Light is particles before passing through double slit

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Observation (Figure 3b): The Photon Chamber shows the photon track (pattern) which shows that the light is photons, not waves.

Conclusion: the light is photons before passing through the double slit.

3.1.2. Double Slit experiment with Beam Splitter (BS)

We will utilize the following rule.

Rule: A Beam Splitter (BS) does not change the behavior of the light.

Example: when a light beam reflected by a BS behaves as particles, then the input light beam behaves as particles, while the transmitted light beam behaves as particles.

Experiment-2 (Figure 4 and Figure 5): We perform the experiment in two setups.

Experimental setup-1: A laser beam partially reflected by BS1 arrives at D1 on detector, and partially transmitted though BS1 arrives at D2 on detector. A larger screen is utilized (Figure 4a).

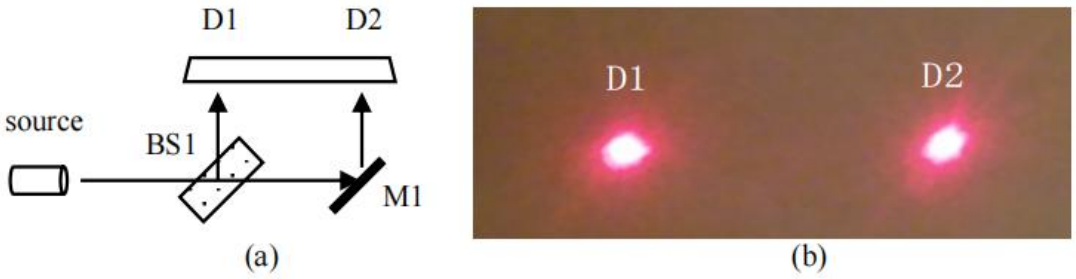

Figure 4. Light is particles before passing through double slit

Observation (Figure 4b): both D1 and D2 show the images of the source.

Conclusion: Rule is proved. Photons detected on both D1 and D2 have the same particle nature. The particle nature of the light is not changed by either being reflected by BS or passing through BS.

Experimental setup-2 (Figure 5a): Insert a slide of double slit between BS1 and M1. The laser light passing through BS1 and the double slit arrives at D2. The light reflected by BS1 arrives at D1.

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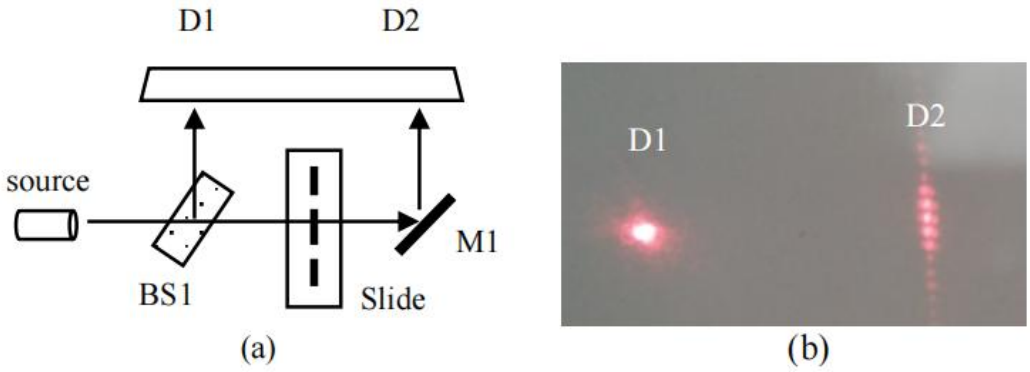

Figure 5. Light is particles before passing through double slit (3)

Observations (Figure 5b): (1) D1 still shows the image of the laser source; (2) D2 shows an interference pattern due to the double slit.

Conclusion: D1 shows the particle nature of the light. Based on Rule, the light passing through BS1 towards the double slit is photons, i.e., before arriving at the double slit, the light is particles.

On the other hand, D1 and D2 show that the Particle pattern and Interference pattern coexist in "the same experiment".

Definition of "the same experiment": To study wave-particle duality and complementarity principle, let us define the term, "the same experiment", as followings: when there is "only one source" emitting light/photons, regardless of the configurations of the experimental apparatus, the experiment is defined as the same experiment.

Experiment-3 (Figure 6): Light is photons before passing through double slit

Experimental setup (Figure 6a): the light passing through BS1/BS2/BS3 and slide-4 arrives at D4; the light reflected by BS1 arrives at D1; the light reflected by BS2 passes through slide-2 and arrives at D2; the light reflected by BS3 arrives at D3.

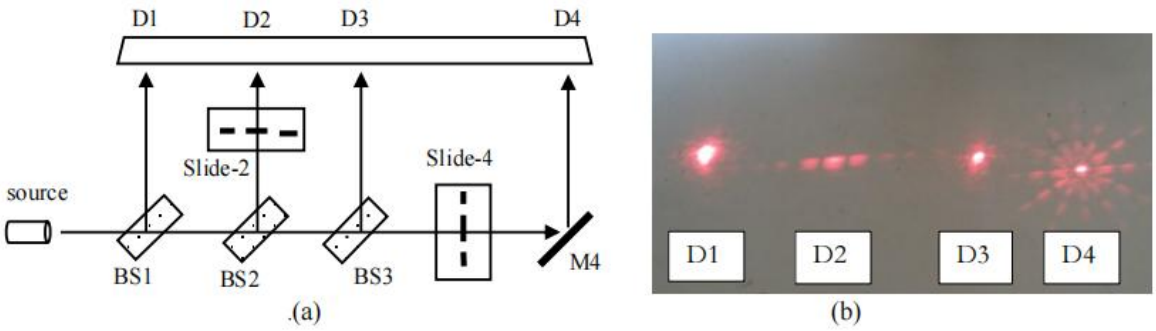

Figure 6. Light is particles before passing through slides of double slit (4)

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Observations (Figure 6b): D1 shows the image of the source, which indicates that the light is particle before passing the slide-2 and slide-4; D2 shows the wave distribution; D3 shows the image of the source, which indicates that the light is particle before passing the slide-4; D4 shows the wave distribution.

Conclusion:

(1) Based on Rule, since the light reflected by BS1 and BS3 behaves as particles, thus, before arriving at slide-2 and slide-4, the light is particles respectively.

(2) Slide-2 and slide-4 convert light's particle nature (before arriving) to wave distribution (after passing through) respectively. The slide determines the behavior of photons only when the light pass through it, but not the behavior before passing it.

(3) The particle nature and wave distribution coexist in the same experiment.

(4) The wave distribution doesn't indicate that the light is wave.

It would be interesting to perform the experiment by emitting photons one at a time.

3.2. Light Is Photons After Passing Through Double Slit

3.2.1. Double Slit Experiment with Photon-Chamber

Experiments with Photon Chamber show the top view of patterns in different Zones.

Experiment-4 (Figure 7):

Experimental setup (Figure 7a): Photon chamber-1, Photon chamber-2 and Photon chamber-3 placed in Zone-1, Zone-2 and Zone-3 respectively. The three photon chambers are 50x50 mm.

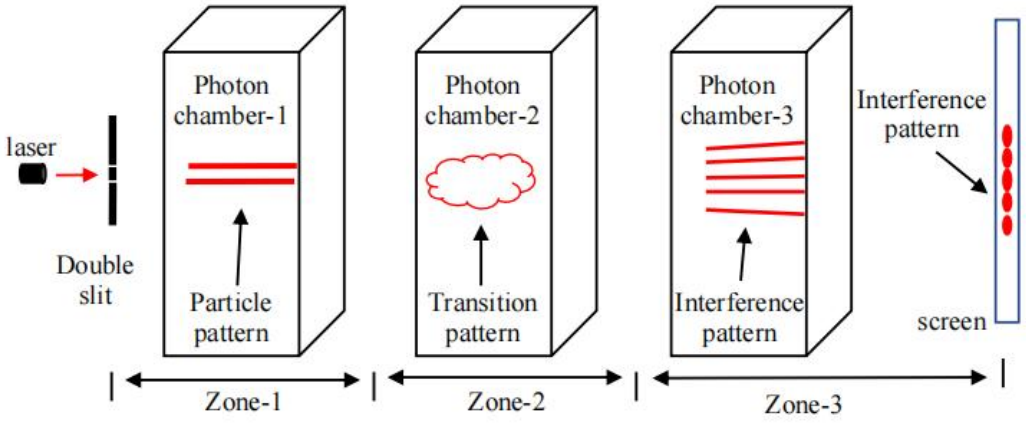

Figure 7a. Experimental setup

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Let us define Particle pattern, Transition pattern and Interference pattern:

1) Particle pattern (Figure 7b): When classical particles going through a double slit, they will form the pattern with the shape of the double slit, referred to it as Particle pattern. A double slit produces the same shape patterns in Zone-1 as two photon tracks in Figure 7b. Thus, we define the pattern of two photon tracks as "Particle pattern" that indicates that the light behaves as particles in Zone-1.

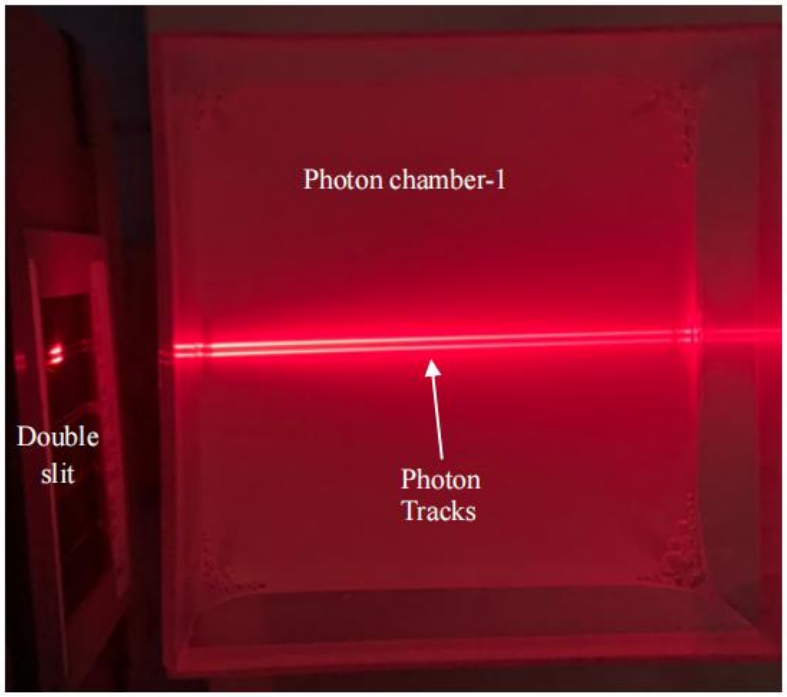

Figure 7b. Photon Tracks --- Particle patterns in Zone-1

2) Transition pattern (Figure 7c): Transition patterns are in between the Particle patterns in Zone-1 and the Interference patterns in Zone-3. When Particle patterns gradually evolve to Interference patterns, they are neither Particle pattern nor Interference pattern and thus, the light behaves not as a wave in Zone-2. We call them the "Transition patterns". The transition pattern is the non-interference pattern.

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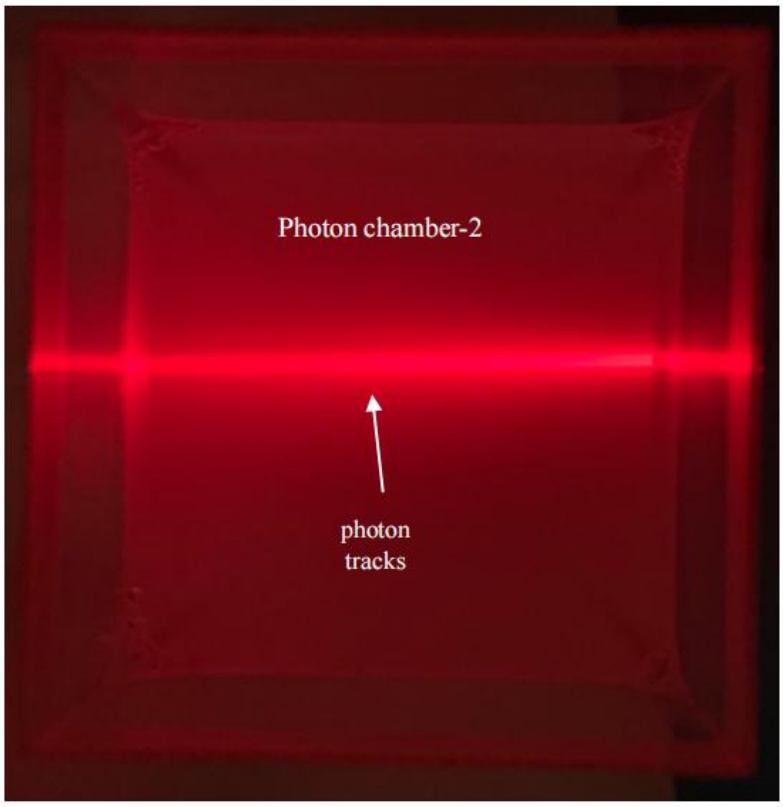

Figure 7c. Transition pattern in Zone-2

3) Interference pattern (Figure 7d): Figure 7d shows the interference pattern.

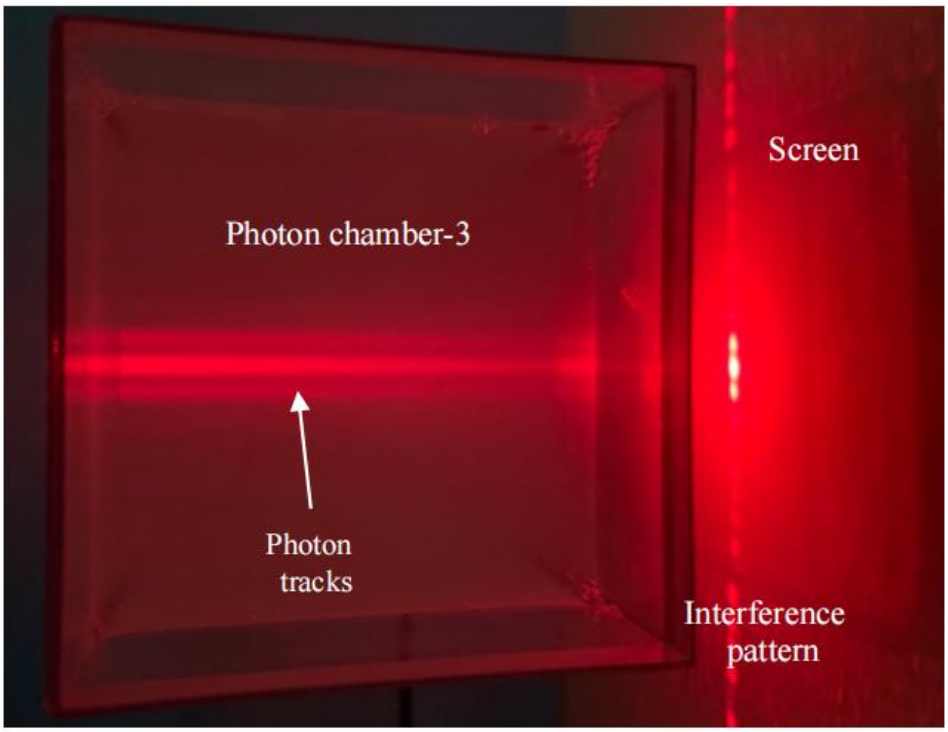

Figure 7d. Interference pattern in Zone-3

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Observation: Photon chamber-1 shows the top view of the photon tracks distributing as Particle pattern. Photon chamber-2 shows the top view of the photon tracks distributing as Transition pattern. Photon chamber-3 shows the top view of the photon tracks distributing as Interference pattern.

Conclusion: Particle patterns and Transition patterns indicate that the light is not waves after passing through the double slit. Figure 7d shows that the light is photons and it is photons that form the interference pattern. Thus, according to Postulate on light (Section 2.2), the light is photons in all four Zones.

To explain "photons distribute as wave" is a challenge.

Note: the boundaries between Zone-1 and Zone-2, and between Zone-2 and Zone-3 are not clear cut. Patterns in one Zone gradually evolve to Patterns in another Zone.

3.2.2. Double Slit Experiment with Shields

Experiment-5 (Figure 8): Light is photons after passing through double slit: two Shields

Experimental apparatus: Two shields form a narrow channel. The purpose is to test whether the channel would prevent the light from interfering if the light would behave as waves in Zone-3. Shield-1 and Shield-2 are 70 inches long, 1.5 inch wide, and 0.3 mm thick.

Experimental setup (Figure 8a): Both Shield-1 and Shield-2 contact the detector.

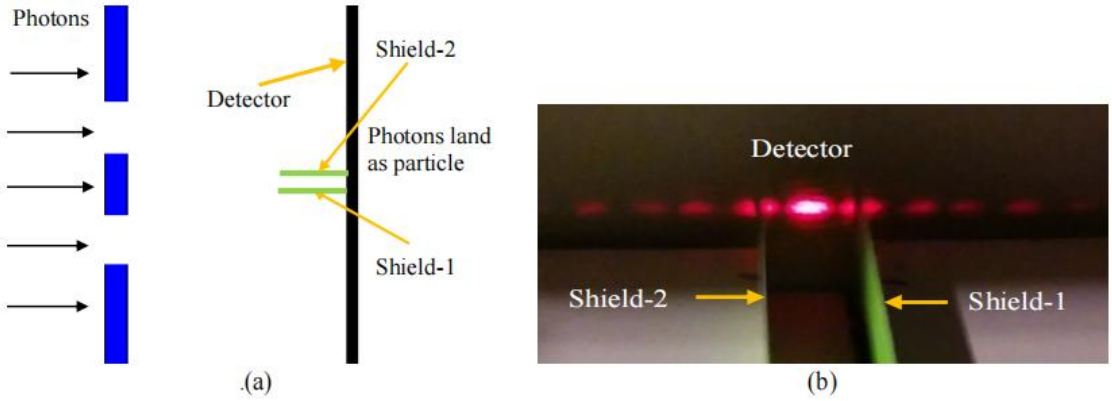

Figure 8. Double slit experiment with two Shields (1)

Observation (Figure 8b): We observe the interference pattern that is the same as there were no shield-1 and shield-2. The existence of two parallel Shields has no effect on the "interference" pattern, which indicates that the light is photons that producing interference pattern on the detector.

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Conclusion: Only the light as particles can (1) pass through the narrow channel; (2) strike at the positions of the zeroth-order fringe and two first-order fringes on the detector; (3) form two projections; and (4) do not disturb the existing interference pattern.

3.2.3. Double Slit Experiment with Blockers

Experiment-6: Light is photons after passing through double slit: Blocker.

Experimental Setup (Figure 9): Blocker-11 and blocker-12 are placed along the normal vector of the surface of the detector and separated by 4 inches.

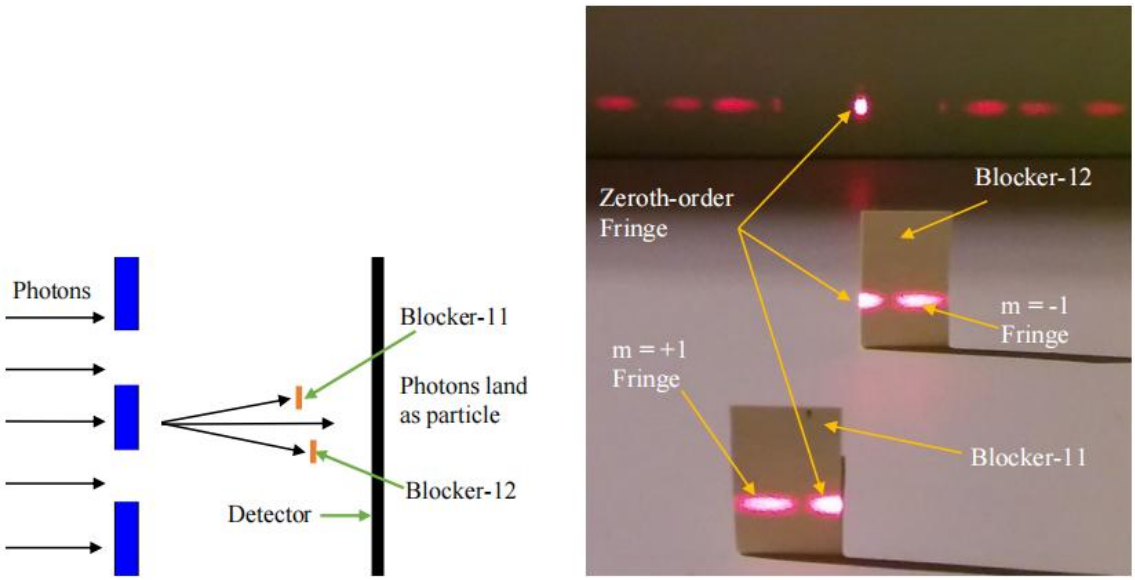

Figure 9 Fringes Formed Independently and Partially

Observation (Figure 9): Two blockers are arranged such that portions of the zeroth-order fringe are formed on the detector, blocker-11 and blocker-12. Thus, the fringe can be formed partially. The existence of each blocker does not affect the fringes formed on other blockers and on the detector. Namely, fringes are formed independently.

Conclusion: Experiment-6 show that_Fringes are formed independently and partially, which would be expected only if the light is particles in Z-3 near the detector. Some of photons form fringes on blockers, while some of photons form partial of the interference pattern on the detector.

Postulate on light is experimentally confirmed.

3.2.4. Double Slit Experiment with Combination of Shields and Blockers

Now let us show the effects of combinations of Shields and Blockers.

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Experiment-7: Testing Postulation on nature of light: combination of Shields and Blocker in two setups.

Experimental Setup-1 (Figure 10a): One end of the channel of shield-1 and shield-2 contact the detector. Place blocker-1 at the other end of shield-1 and shield-2, where we denote it as Entrance (Figure 10b).

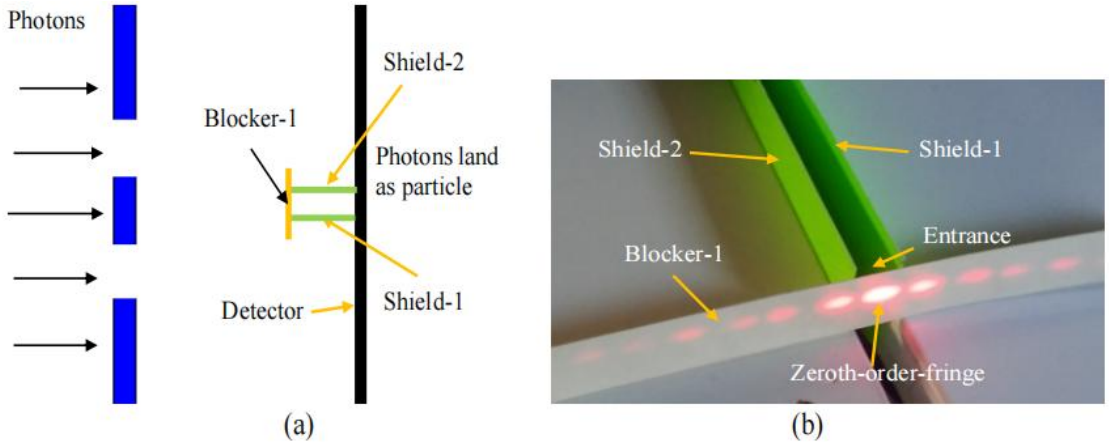

Figure 10a and 10b. Testing Postulate on light with Shields and Blocker

Observation (Figure 10b): The interference pattern is formed on blocker-1 instead of the detector.

Experimental Setup-2 (Figure 10c): Cutting the top portion of blocker-1.

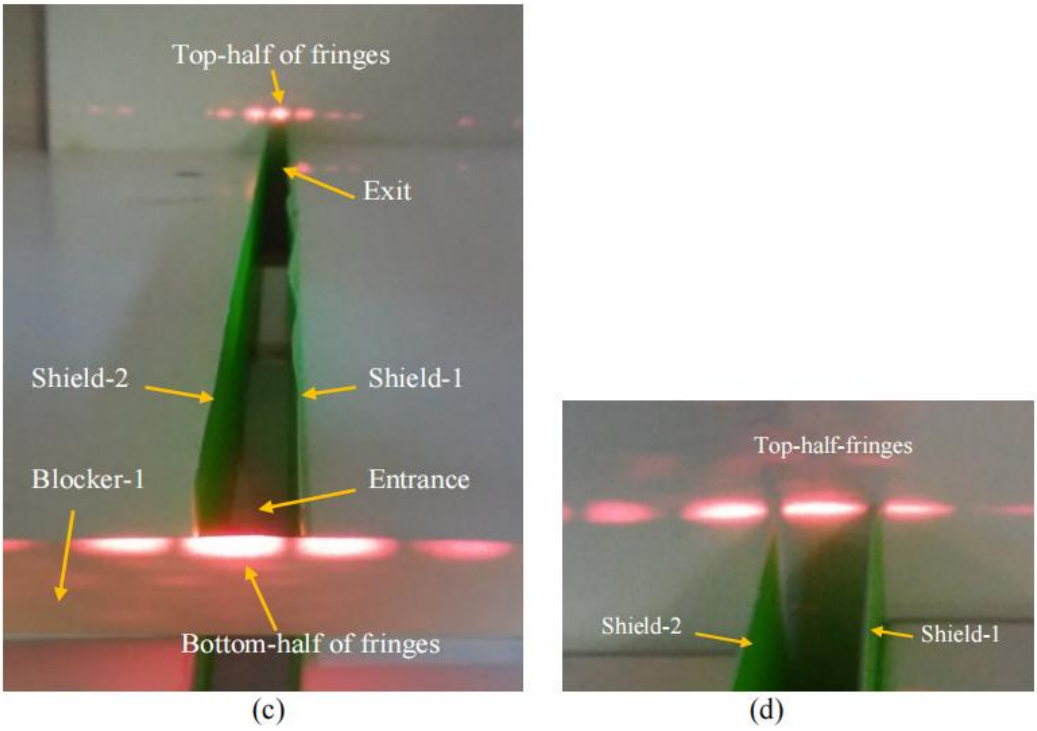

Figure 10c and 10d Testing Postulate on light: Cut Top Half of Blocker-1

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Observation (Figure 10c and 10d): The bottom half of the fringes still appears on blocker-1, while the top half of the fringes appears on the detector. Namely each fringe is formed partially. Shields have no effect on the interference pattern at all.

Experiment-3.8 (Figure 11):

Testing Postulate on light with Shields and Blocker. We perform this experiment in two setups.

Experiment Setup-1 (Figure 11a): Insert transverse blocker-2 one inch wide into the channel formed by shield-1 and shield-2.

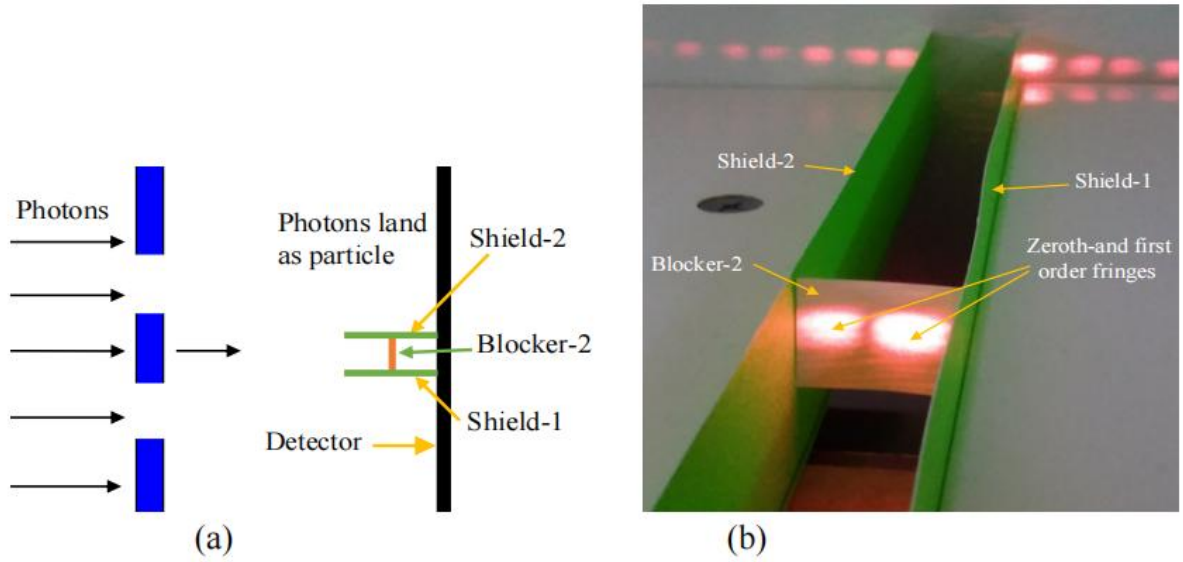

Figure 11a and 11b. Blocker-2 in Channel

Observation (Figure 11b): Two fringes are formed on blocker-2, and the remaining fringes are formed on the detector. Namely, Fringes are formed independently. Two shields have no effect on the interference pattern. This observation indicates that the light is particles.

Experimental Setup-2 (Figure 11c): Cut two triangles on blocker-2 at the locations of the zeroth-order fringe and a first-order fringe respectively. Then place blocker-2 into the channel.

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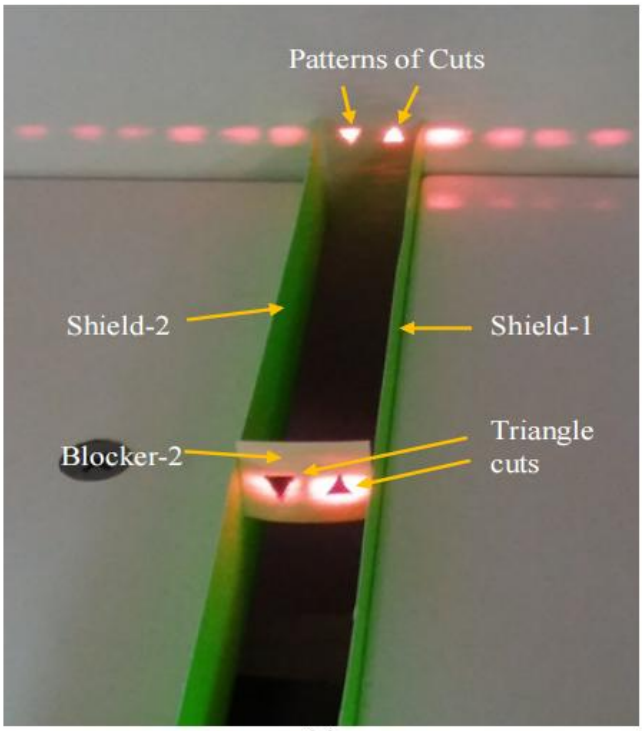

Figure 11c. Blocker-2 with Two Cuts

Observation (Figure 11c): The light passes through two triangle-shaped cuts and forms exactly the same triangle-shaped patterns on the detector, which shows the particle nature of the light, namely, photons move along straight lines. Note that photons are not directly from the source; they just pass through a double slit and, if we adopt the wave theory, are supposed to behave as waves.

Conclusion: The light is particles. Postulate on light is confirmed experimentally.

3.2.5. Double Slit Experiment with Conductive Metal Tube

Experiment-9: Testing Postulate on light and EM theory of light

Experimental setup (Figure 12a): In this setup, an Aluminum (AL) rectangular tube of 0.75x1.12x48 inches is used.

Observation (Figure 12): Figure 12b shows the interference pattern without AL tube. Figure 12c and 12d show the unaffected interference patterns. Figure 12d also shows the projections of the two side walls of the AL tube.

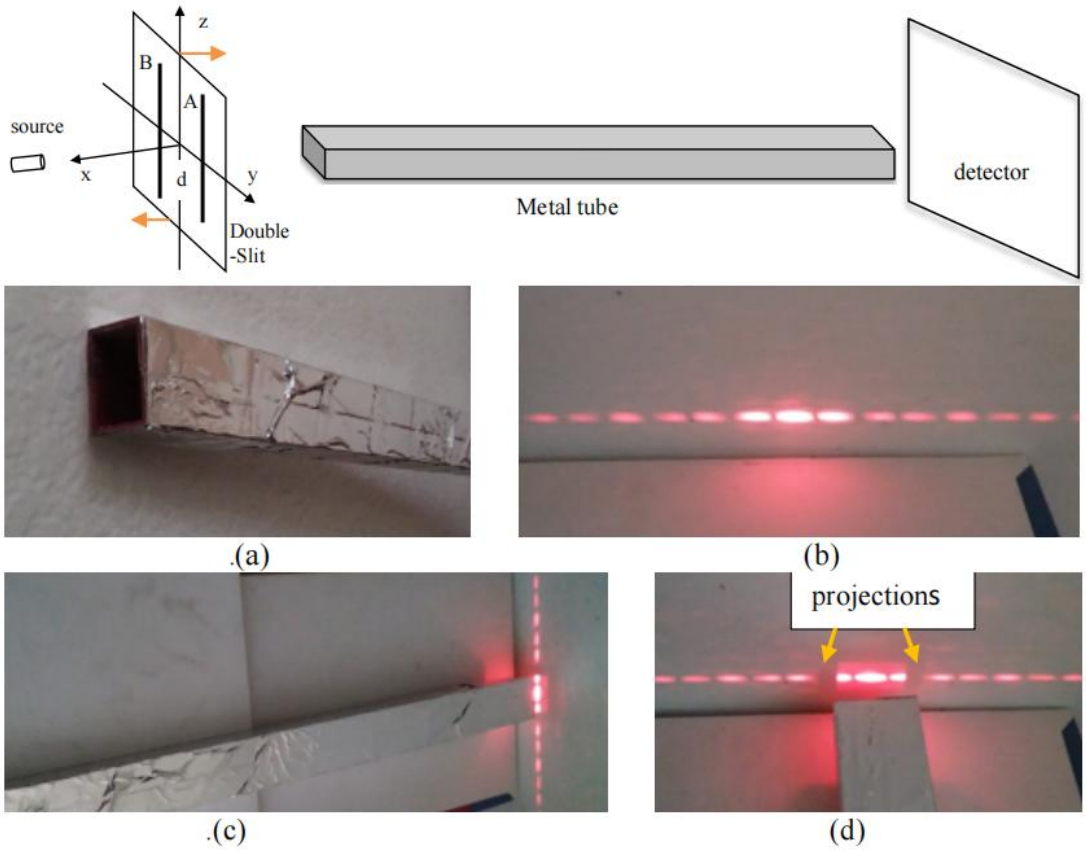

Figure 12. Aluminum-tube-shield and interference pattern

Conclusion: The conductive metal tube has no effect on the interference pattern, which indicates that the light is not the electromagnetic (EM) waves.

3.2.6. Double Slit Experiment with Lens

Experiment-10: Double slit experiment

To study the nature of the light after passing through the double slit, we utilizing a lens.

Experimental setup: the left of Figure 13 shows the experimental setup.

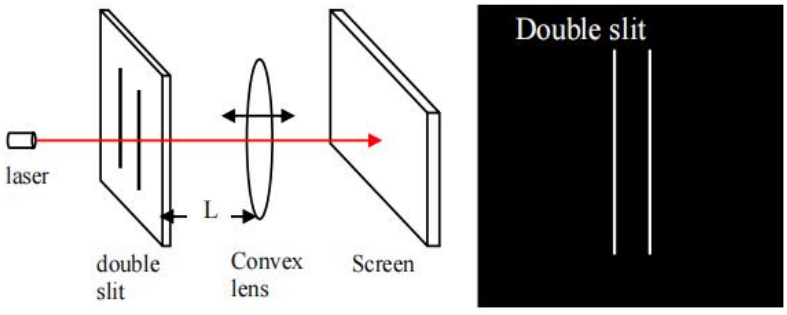

Figure 13. Experimental setup and double slits

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When placing the lens at different positions L, we have the following patterns that shows: (1) the light is photons after passing through the double slit (from L = 10 mm to L = 600 mm); (2) the Particle patterns gradually evolve to the Interference patterns (at L is equal and larger then 750 mm).

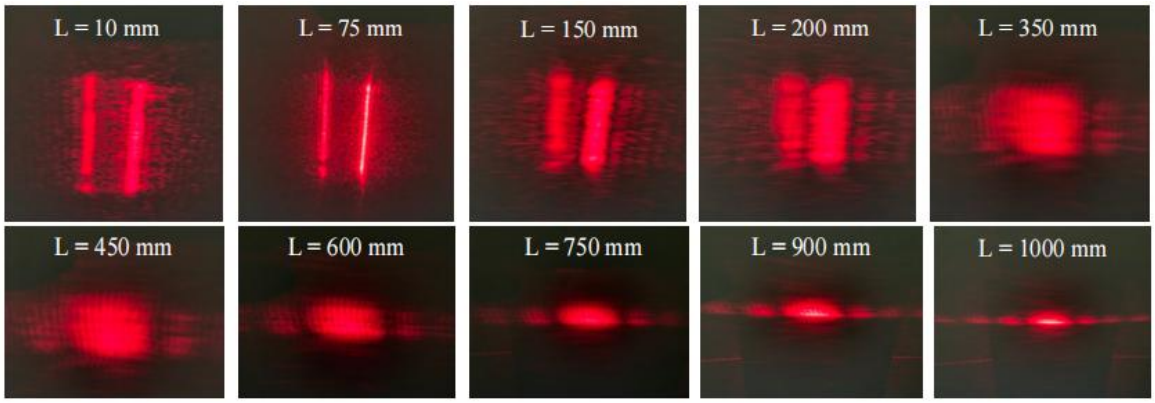

Figure 14. Evolution of patterns of double slit experiment

Observation (Figure 14): When L = 75 mm, the vertical pattern is the typical image of double-slit, Particle pattern. When L = 350 mm, the pattern is the typical Transition patterns. Both the Particle pattern and the Transition patterns are the non-interference patterns and thus, indicate that the light is particles after passing through the double slit. When L ≥ 750 mm, the patterns are the horizontal interference patterns.

Conclusion: according to Postulate on light, the light is photons after passing through the double slit, and photons form both the non-interference pattern and the interference pattern.

Note: The Particle patterns gradually evolve to the *orthogonal* interference patterns.

3.2.7. Discussion on "Collapse of Wave Functions"

In Zone-0, Zone-1, Zone-2 and on the surface of the screen, the light is particles. According to the Postulate on light, the light in Zone-3 is photons as well. And Photons as particles distribute as wave-like pattern in Zone-3 and on the surface of the screen.

According to the standard concept of the "Collapse of wave functions", in the area of Zone-3 near the screen, for example, 1 nm (which is "huge" comparing to the "0 dimension of photon") from the surface of the screen, the light is still waves of, for example, 650 nm wavelength. Then once the light crosses the distance of 1 nm and lands on the surface of the

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screen, the wave functions of the light immediately disappeared and the light becomes photons. This process has the name “Collapse of Wave Functions”.

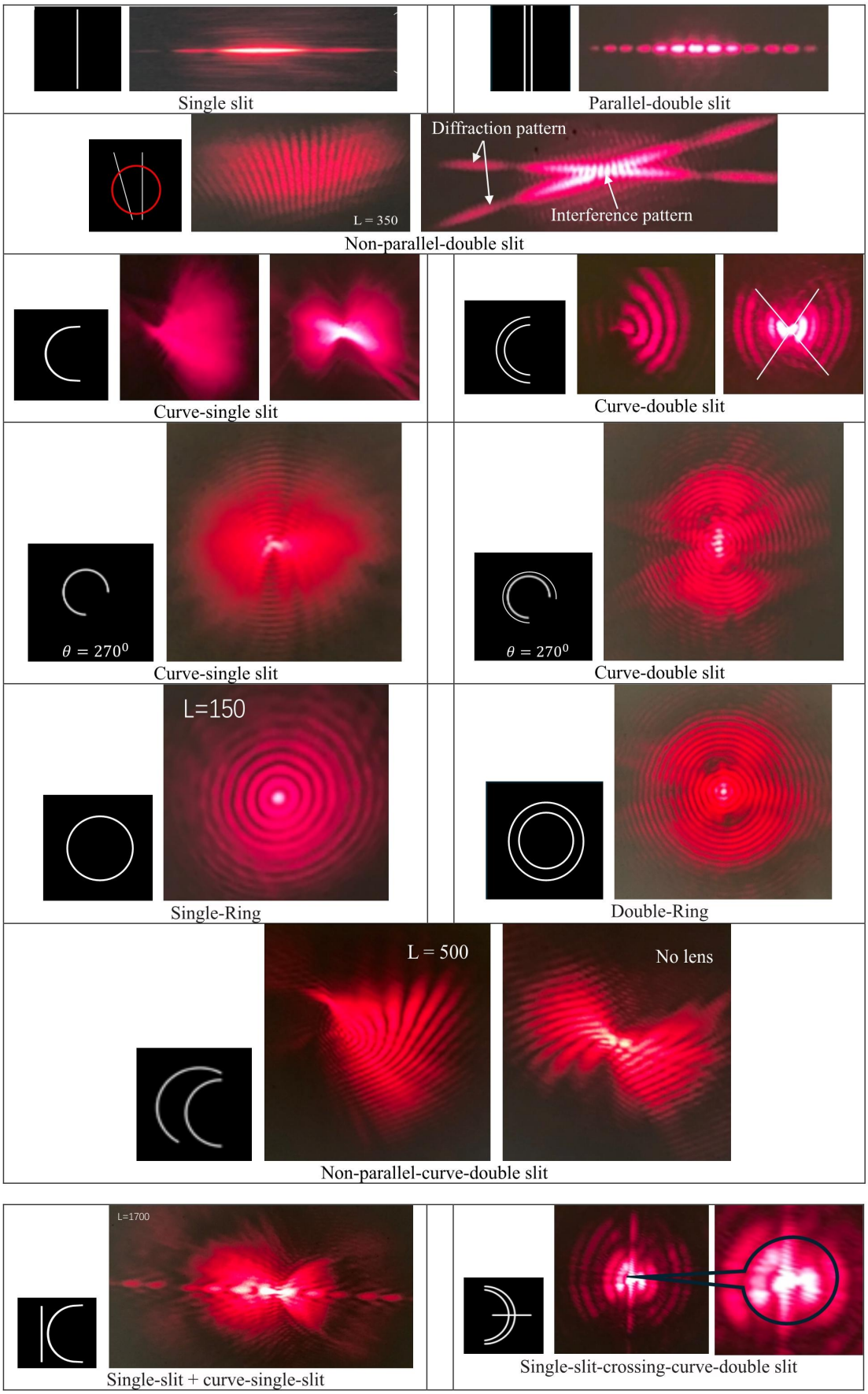
To explain the mechanism of “*Collapse of Wave Functions*” is a challenge [6].

According to the Postulate on light, the light is Photons in all Zones of the double slit experiment, there is no need to introduce the concept of the “Collapse of Wave Functions”.

4. Universality of Light Being Photons in Wave Experiments: Optics-Butterfly-effect

Several other experiments show (Figure 2): (1) the light is particles and it is the particle that produce wave patterns, i.e., the PhotoWave phenomena are universal. (2) The differences in the structure of the slits lead to significant differences in the patterns, referred to as the Optics Butterfly-effect. (3) Each of the curve-single slit, the curve-double slit, the non-parallel-double slit and the non-parallel-curve-double slit produces two different interference patterns in the same experiment respectively.

Table 2 Universality of PhotoWave Phenomena



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5. Discussion and Conclusions

The phenomena of all comprehensive double slit experiments in this article are consistent. The phenomena of the non-interference patterns evolving to the interference patterns are universal and mystery.

To perform the comprehensive double slit experiments with single photon would test the conclusion of this article.

The comprehensive double slit experiments show that the light is particles, and it is the particles form the wave-distribution of the light, the PhotoWave phenomena.

The comparisons between the PhotoWave phenomena and the classical wave theory of the light are shown in Table 2**.**

Table 3. PhotoWave phenomena vs classical wave theory of light

	Zone-0	Zone-1	Zone-2	Zone-3	Detector	Challenge
Classical wave theory	wave	wave	wave	wave	Photons form wave pattern	Collapse of wave function
PhotoWave phenomena	photons form non-wave pattern	photons form non-wave pattern	photons form non-wave pattern	photons form wave pattern	photons form wave pattern	Mechanism of Photons form wave-pattern

To interpret consistently the comprehensive double slit experiments and the PhotoWave phenomena is a challenge.

Table 3 shows how the PhotoWave phenomena affect the understanding of the nature of the light.

Table 4. PhotoWave phenomena demanding interpretation

Light is Particle	**Electron is particle**
1704 Newton (theory) 1887 Hertz (experiment) 1905 Einstein (theory) 2021- Comprehensive Young double slit (PhotoWave phenomena)	1897 Thomson (experiment) 2015 Waldie (experiment) (Electrons produce wave pattern)
Demanding Interpretation of Particles distributing as wave	

We show the PhotoWave phenomena for further studying: (1) the nature of the light. (2) the classical optics. (3) the quantum theory of the light.

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