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Research Article

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Non-Interference Pattern Evolving to Interference Pattern, Non-Diffraction Pattern Evolving to Diffraction Pattern, and Two Non-Diffraction Patterns Evolving to Diffraction-Interference-Hybrid Pattern -Advances in Optical Experiments Demanding New Theory

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Abstract

We experimentally show novel phenomena: (1) in the same double slit or cross double slit experiment, within macroscopic distances from diaphragm, the patterns are non-interference and gradually evolve to the interference patterns near the screen; (2) in the same single slit or cross single slit experiment, within macroscopic distances from diaphragm, the patterns are non-diffraction and gradually evolve to the diffraction patterns near the screen; (3) in the same non-parallel-two-slits experiment, within macroscopic distances from diaphragm, the patterns are diffraction and gradually evolve to the diffraction-interference-hybrid patterns; (4) the diffraction-interference hybrid patterns are angle-dependence. To interpret consistently above phenomena is the challenge to the existing wave theories of the physical optics. Advances in optical experiments demand new theory.

Keywords: Double Slit Experiment, Cross-Double Slit Experiment, Single Slit Experiment, Cross Single Slit Experiment, Pattern Evolution, Interference Pattern, Non-Interference Pattern, Diffraction Pattern, Non-Diffraction Pattern, Interference-Diffraction Hybrid Pattern

1. Introduction

The double slit interference phenomena and the single slit diffraction phenomena are two basic phenomena in the physical optics. The first double slit experiment was performed by Young in 1801 [1], which revived the Huygens wave theory of light [2], and, 100 years later, led to wave-particle duality. Feynman called it "a phenomenon […] has in it the heart of quantum mechanics. In reality, it contains the only mystery [of quantum mechanics]" [3]. Moreover, the nature of photons truly 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?" [4].

There are mainly three interpretations of the double slit experiment: the standard optical wave interpretations, the electromagnetic (EM) wave interpretations, and the quantum probability wave interpretations:

(1). The classical optical wave description (Figure 1.1): $y = m\lambda L/d,$ where $L \gg d \gg \lambda$, "y" is the distance between the center of the zero fringe to the center of the m-fringe; "L" along the x axis is the distance between the double slit and the screen; "d" is the spacing between two slits. The separation between two fringes is proportion
to $\Delta y \propto 1/d.$

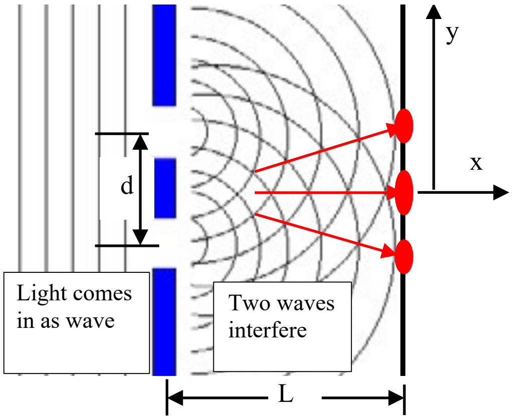


Figure 1.1. Standard Wave Interpretations of double slit experiment

(2). The electromagnetic (EM) wave description is: $I = \mathrm{E}_1^2 + \mathrm{E}_2^2 + 2\mathbf{E}_1 \cdot \mathbf{E}_2$, where $\mathbf{E}_1$ and $\mathbf{E}_2$ are the electric fields at the slit-1 and the slit-2 respectively, I is the intensity. The EM waves are coherent plane waves.

(3). The probability wave description: $P_y = |\psi_1(r)|^2 + |\psi_2(r)|^2 + 2Re[\psi_1^*(r)\psi_2(r)]$, where P_y is the probability of observing a photon on the screen. $\psi_1(r)$ and $\psi_2(r)$ are the wave functions of the photons passing through the slit-1 and slit-2, respectively.

For the single slit experiments, the mathematical descriptions have the similar forms:

(4). The classical optical wave description is: $y = m\lambda L/a$, where "a" is the width of the single slit.

(5). The EM wave description is: $I = \langle \boldsymbol{E}^2 \rangle$, where $\boldsymbol{E}^2$ is the electric fields at the slit.

Note: as shown in Figure 1.1, the two slits are perpendicular to the x-y plane which crosses the double slit. Above interpretations/equations show that the thickness of the cross-section is irrelevant, and two slits are parallel. In this article, we experimentally show novel phenomena: (1) in the same double slit/cross double slit experiment, within macroscopic distances from diaphragm, the patterns are non-interference and gradually evolve to the interference patterns near the screen; (2) in the same single slit/cross single slit experiment, within macroscopic distances from diaphragm, the patterns are non-diffraction and gradually evolve to the diffraction patterns near the screen; (3) in the same non-parallel-two-slits experiment, within macroscopic distances from diaphragm, the patterns are diffraction and gradually evolve to the diffraction-interference-hybrid patterns; (4) the diffraction-interferencehybrid patterns are angle-dependence.

To interpret consistently above experimental phenomena is the challenge to the existing wave theories of the physical optics.

Novel experiments bring the search for the new physical optics.

2. Non-Interference pattern evolving to Interference pattern

For convenience, we introduce four Zones and corresponding terms of the patterns in each Zone: Particle pattern in Zone-1, Transition pattern in Zone-2, Interference pattern or Diffraction pattern in Zone-3.

2.1. Four Zones

Let us divide the space between the light source and screen into four Zones (Figure 2.1) [5]:

(1) **Zone-0:** between the source and the double slit, in which the pattern is non-wave;
(2) **Zone-1:** near the double slit, in which the pattern is non-interference, referred the pattern as the ***Particle pattern***;
(3) **Zone-3:** near the screen, in which the patterns are ***Interference patterns or Diffraction patterns***;
(4) **Zone-2:** transition Zone, between Zone-1 and Zone-3, in which Particle pattern evolves to Interference pattern or Diffraction pattern, referred the patterns as the ***Transition patterns*** that are also the non-interference or non-diffraction.

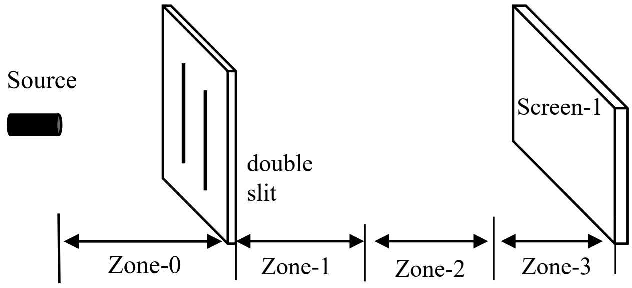


Figure 2.1. Four Zones

2.2. Experiments with Photon-chamber

For studying the behavior of the light near the double slit, we introduce Photon Chamber that is a transparent container filled with mix of water and fine powder. The fine powder reflects photons to be observed [5].

Experiment-2-1:

Placing the photon chamber in Zone-1, Zone-2 and Zone-3, respectively (Figure 2.2).

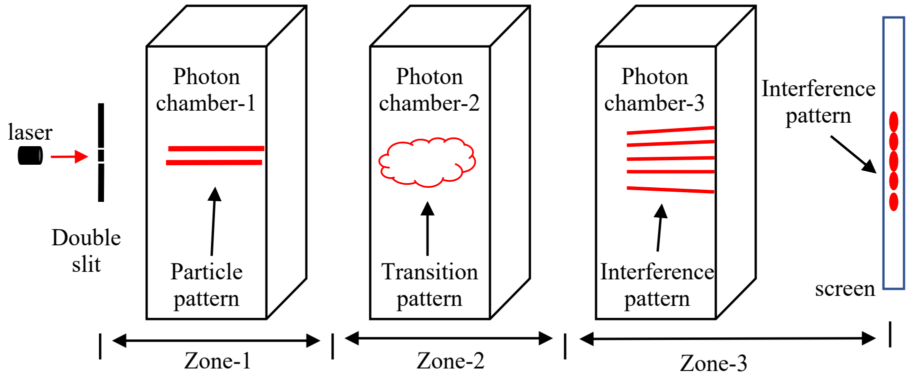


Figure 2.2. Double slit experiment with photon chambers

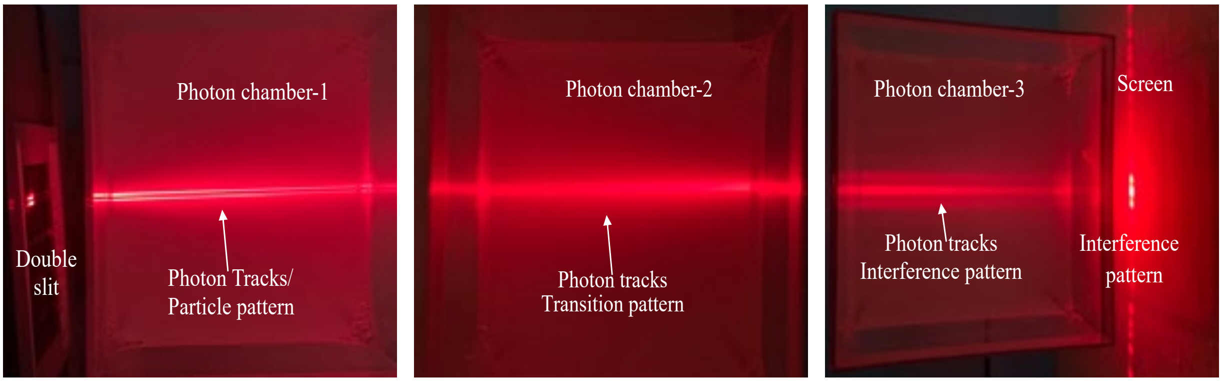


Figure 2.3. Double slit experiments: Non-coherent Photons becoming Coherent Photons

Observation (Figure 2.3 shows the top view): The patterns shown in Photon chamber-1, Photon chamber-2 and Photon chamber-3 are Particle pattern, Transition pattern and Interference pattern, respectively. Particle pattern and Transition pattern are non-interference patterns.

Discussion: Photon chamber-1 in Zone-1: Particle pattern contains two photon tracks, which indicates that up to certain macroscopic distance, the light is photons and propagates along the straight-line trajectories that do not distribute as waves. Photon chamber-3 in Zone-3: the photon tracks in Photon chamber-3 show that the light is photons, and the photon tracks distribute as wave. On the screen, we observe the standard interference pattern, which indicates that the photons distribute as coherent waves. Since the photons in Zone-1 and Zone-2 produce the non-interference patterns (although we assume the photons have the same frequency and same phase), for convenience, we name them as "non-coherent photons". Then, the non-coherent photons evolve to the coherent photons (in Zone-3) that produce the interference patterns, which is the reverse process of "decoherence". Photon chamber-2 in Zone-2: the shapes of the photon tracks in Photon chamber-2 cannot to be described. Thus, for study the Transition pattern, we introduce the lens in Section 2.4.

We referrer this phenomenon as "Non-interference pattern evolving to Interference pattern".

2.3. Experiment with Blocker/Shield

To prove that the light is photons near the screen in the double slit experiments, we perform the following experiments [6].

Experiment-2-2 (Figure 2.4): Double slit experiment with blocker

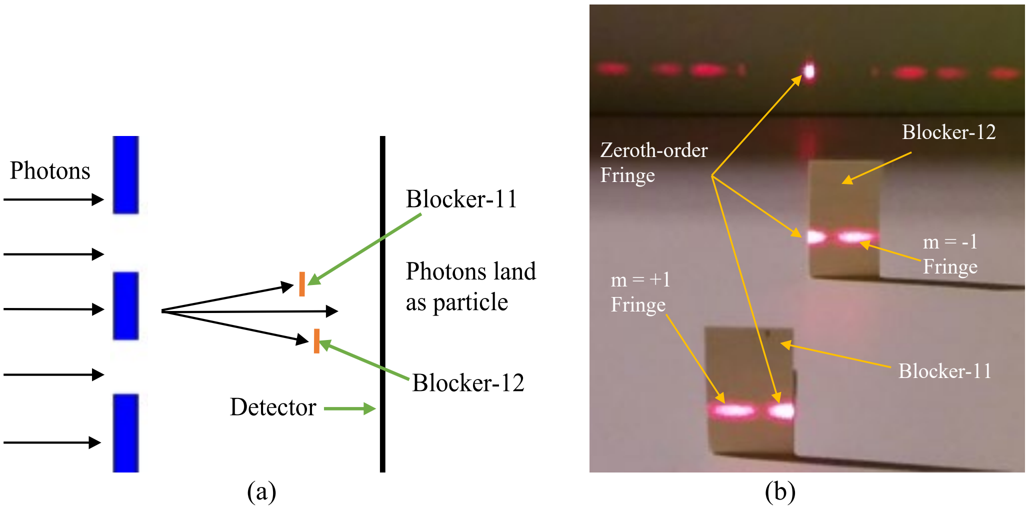


Figure 2.4. Double slit experiment with blockers

Observation (Figure 2.4b): Two blockers are arranged such that portions of the zeroth-order fringe are formed on the detector/screen, blocker-11 and blocker-12, respectively, which indicate that 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.

Experiment-2-3 (Figure 2.5): Double slit experiment with shield and blocker

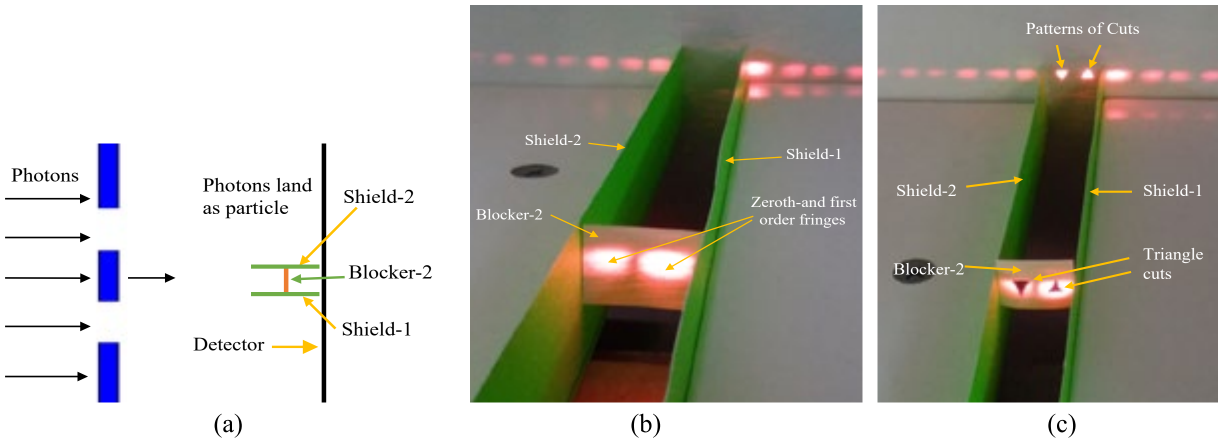


Figure 2.5. Double slit experiment with two shields and blocker

Observation: Figure 2.5b shows that two fringes are formed on blocker-2, and the remaining fringes are formed on the detector. Namely, Fringes can be formed independently. Two shields have no effect on the interference pattern. This observation indicates that photons behave as particles near the detector/screen.

Figure 2.5c shows that Photons pass through two triangle-shaped cuts and form exactly the same triangleshaped patterns on the detector, which indicates that photons move along straight lines, which indicates the particle nature of photons; the fringes are formed partially and independently.

Note that the photons are not directly from the source; they are just pass through a double slit and, according to the standard wave interpretation, they should be waves.

The conclusion is that photons behave as particles.

Experiment-2.4. Figure 2.6a shows the experimental setup.

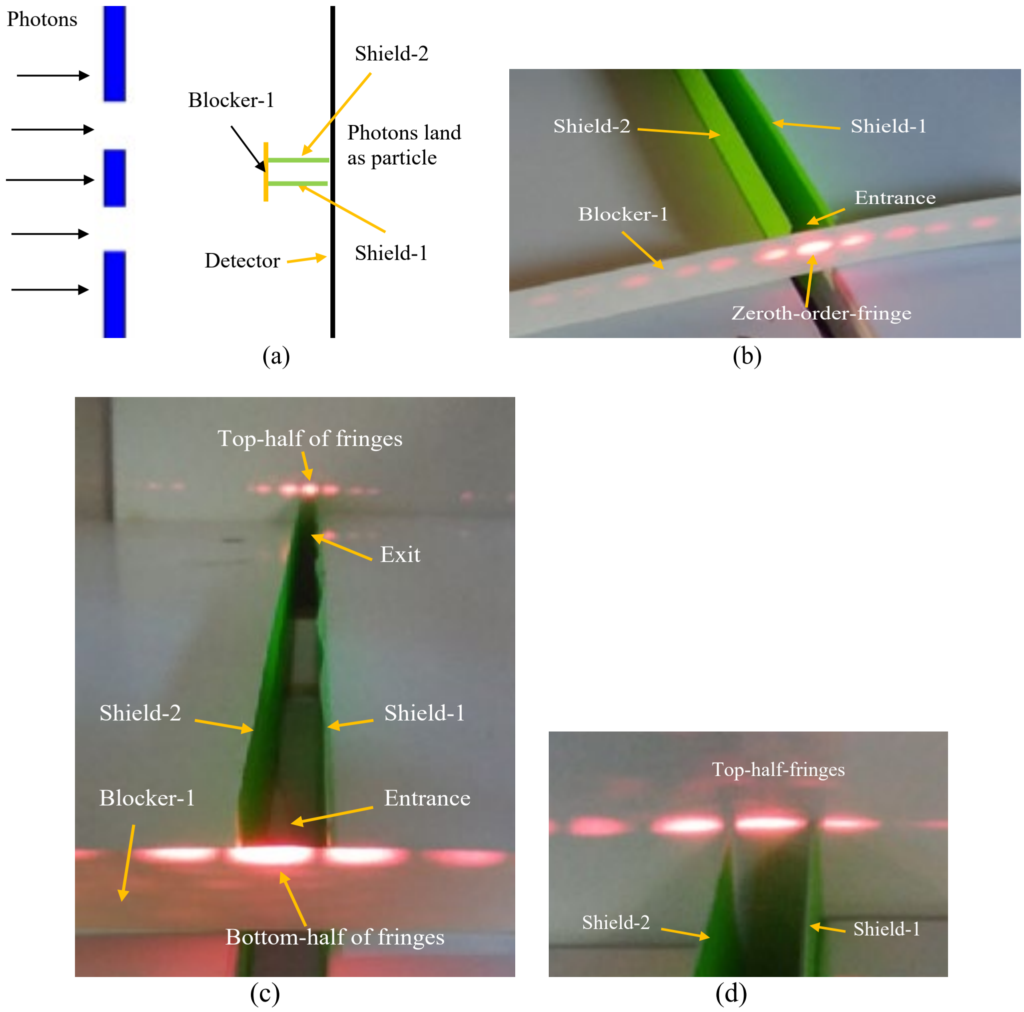


Figure 2.6. Double slit experiment with two shields

Observation: Figure 2.6b shows that the interference pattern is formed on blocker-1 instead of the detector. Then cutting the top portion of blocker-1. Figure 2.6c and 2.6d show that the bottom half of the fringes still show on blocker-1, while the top half show on the detector. Namely each fringe can be formed partially. And shields have no effect on the interference pattern.

Discussion: Experiment-2.1 to Experiment-2.4 are consistent, and indicate that in the double slit experiments, the light is photons, and it is photons that distribute as wave on the detector/screen.

The existing wave theories of physical optics cannot interpret Experiment-2.1 to Experiment-2.4 and thus, are incomplete, and new complete theory is required.

2.4. Experiments with lens

2.4.1. Postulates on Lens in wave experiments

Experiment-2.1 shows that Photon chamber shows only the top view of the patterns. To study the details of the pattern evolution, we utilize the convex lens. In the classical wave experiments, the light passing through the double slit has the certain pattern. As shown in Experiment-2-1, the pattern changes with the distance from the diaphragm, i.e., the patterns are evolving with distance. To study the evolution of the patterns, we place the convex lens at different positions and thus, the light patterns arriving at the input surface of the convex lens are different,
i.e., the patterns arriving at the input surface of the convex lens change.

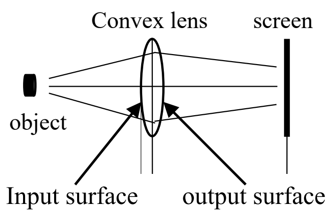


Figure 2.7. schematics of postulate on convex lens

For the double slit/cross double slit experiment, the image of the object is the light just comes out the double slit/cross double slit. The input image is the pattern arriving at the input surface of the convex lens (Figure 2.7). Both images are different.

To utilize the convex lens to study the evolution of patterns, we propose new Postulates of convex lens.

Postulates [5]:
First Postulate: the convex lens enlarges the input image that arrives at the input surface;
Second Postulate: The convex lens breaks the evolution of the patterns;
Third Postulate: The convex lens does not change the nature of the input pattern.

2.4.2. Experiments: Experiments in this article confirm Postulates.
Experiment-2-5: Double slit experiment: the left of Figure 2.8 shows the experimental setup.

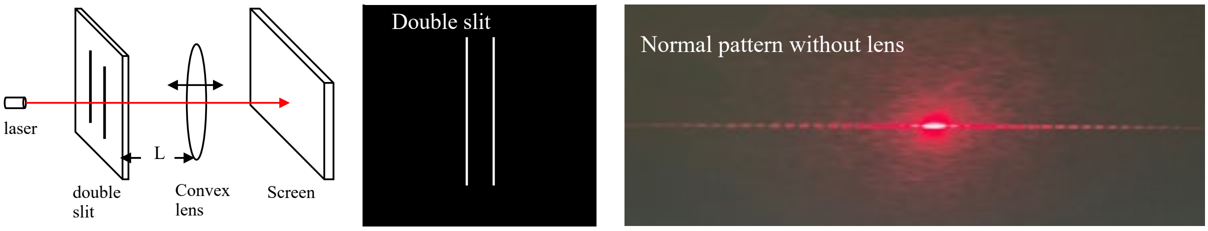


Figure 2.8: Left: experimental setup; Right: double slits and its standard pattern without lens When placing the lens at different positions L, we have the following patterns evolution.

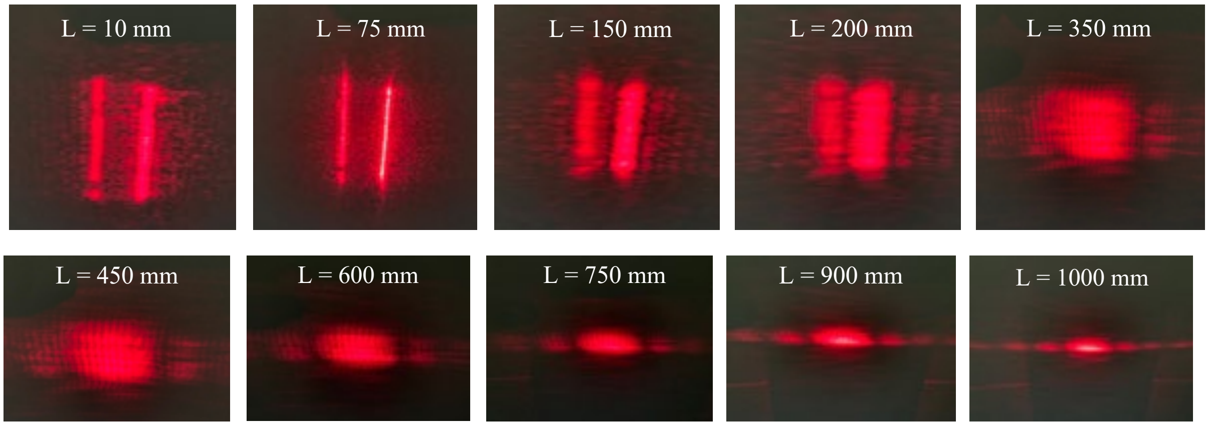


Figure 2.9: Evolution of patterns of double slit experiment

Observation (Figure 2.9): at L = 10 mm, the pattern is Particle pattern, which is the non-interference patterns.
When L = 75 mm, the Particle pattern is the typical image of double-slit. When L = 350 mm, we referred the patterns as Transition patterns. When $L \geq 750$ mm, the patterns are the interference patterns.
The vertical Particle patterns gradually evolve to the orthogonal interference patterns.
Note: approximately, from L = 10 mm to L = 150 mm, the patterns are all Particle patterns.

Discussion: Particle pattern evolving to orthogonal Interference pattern (Figure 2.10)

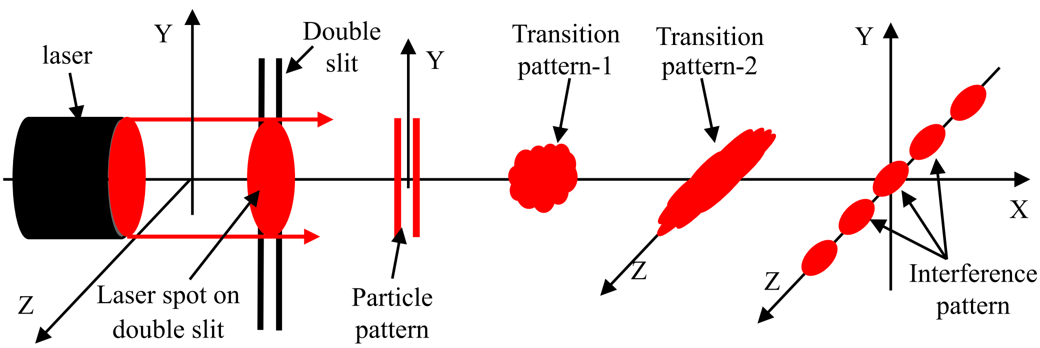


Figure 2.10. Particle patterns evolving to orthogonal interference pattern

1) The double slit is in Y-Z plane and along Y axis
2) Particle pattern is in Y-Z plane and along Y axis, which has the same length in Y direction as that of the double slit
3) Transition pattern-1 is in Y-Z plane, which has the similar dimensions in both Y and Z directions.
4) Transition pattern-2 is in Y-Z plane: in Y direction, the dimension of Transition pattern-2 shrinking, while in Z direction, the dimension of Transition pattern-2 expanding
5) Interference pattern is in Z-direction. In addition to the Feynman's mystery of the double slit experiment, the new mysteries are:
(1) Particle pattern (the non-interference pattern) gradually evolving to the interference pattern;
(2) the Particle pattern along Y direction evolving to the Interference pattern along Z direction.
The challenge is to consistently interpret the new mysteries.

Experiment-2-6: Two double slits crossing at right angle
Figure 2.11 shows the experimental setup, cross double slit, and interference pattern without lens.

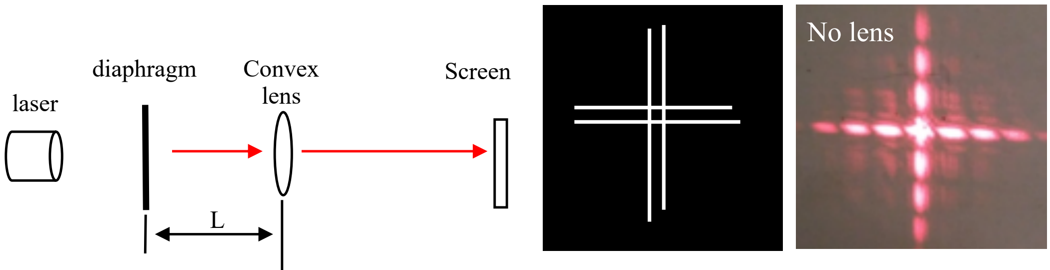


Figure 2.11: Experimental setup for cross double slit experiments

Placing the lens at different distance L. We observe the evolution of the patterns (Figure 2.12).

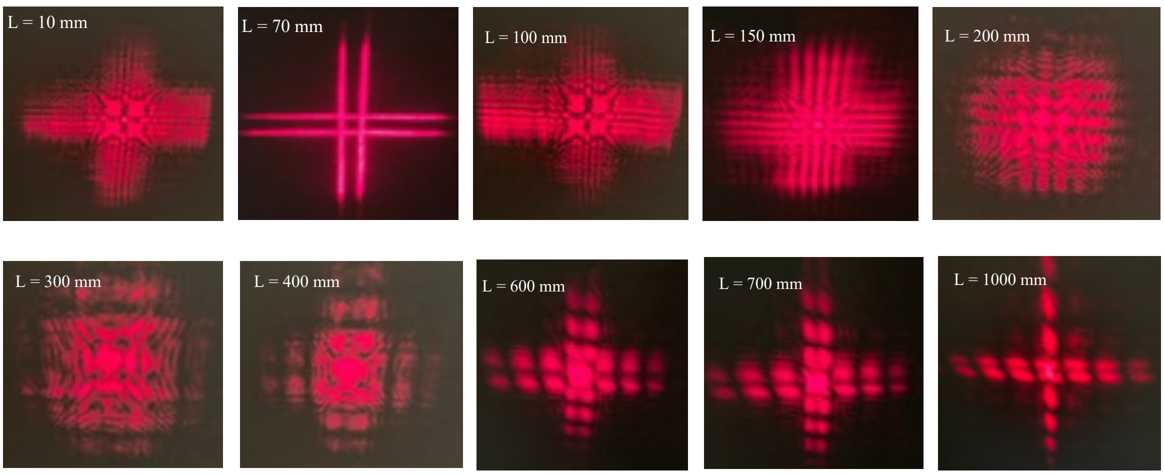


Figure 2.12. Pre-Particle pattern evolving to Interference pattern

Observation (Figure 2.12): at L = 10 mm, the pattern is Pre-Particle pattern; at L = 70 mm, the patterns is Particle pattern; Then, when $L \geq 100$ mm, Particle pattern gradually evolves to the Transition pattern, and final evolve to the interference pattern at L = 1000 mm.

The double slit-AB and -CD are in different orientations, so there is Pre-Particle pattern.

Discussion-1 (Figure 2.13): Let us enlarge the intersection of double-slit-AB and double-slit-CD, as shown in Figure 2.13. The intersection has the shape of square. Four small dots, denoted as "a/c", "b/c", "b/d" and "a/d", represent the four corners of the intersection. Except the double-slit-AB and double-slit-CD, all of other area (including the shadow square) is the opaque area. The intersection of slit-A and slit-C is denoted by a "Red square".

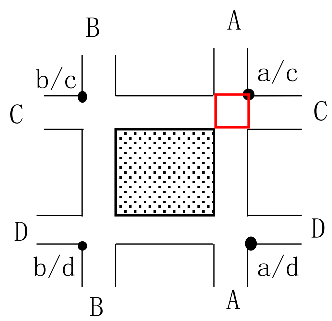


Figure 2.13: Cross center of Double slit-AB crossing double slit-CD

The cross-section of the laser beam is a circular with a diameter slightly larger than the dimension of the intersection area. The majority of photons will land on the opaque area, mainly the shadow square, while minority of photons will pass through both double-slit-AB and double-slit-CD.

According to the regular interpretation of 1D-double-slit experiment, photons passing through the slit-A (slit-B) will interfere with photons passing through the slit-B (slit-A), while photons passing through the slit-C (slit-D) will interfere with photons passing through the slit-D (slit-C).

Since emitted photons have the same optical parameters, the challenge to the standard interpretation of 1Ddouble- slit experiments is to explain the following questions:

(1) Why do photons passing through the slit-A (slit-B) interfere with photons passing through the slit-B (slit-A), but not interfere with photons passing through the slit-C (slit-D), even when which are closer. Similarly, why do photons passing through the slit-C (slit-D) interfere with photons passing through the slit-D (slit-C), but not with photons passing through the slit-A or slit-B, even when which are closer.

(2) When the photons pass through the "Red square", there are two questions:

(2-1): how the photons determine whether they are passing through slit A or slit C?

(2-2): how the photons determine which photons they should interfere with, the photons passing through slit-B or the photons passing through slit-D.

(2-3): whither the photons passing through the "Red square" would interfere with each other?

If one treats photon as a "person" as in the interpretation of delayed-choice-double-slit experiment, then the challenges are to explain the following questions:

(1) How do photons "sense" which slit they would pass through;

(2) How do photons "sense" which portion, i.e., the inside-portion or the outside-portion, they would pass through;

(3) how do the photons passing through a slit "find" photons passing through its "paired slit" to interfere and create the interference-pattern accordingly;

Discussion-2: About the interpretation of the behavior of photons emitted one at a time:

In this experiment, a photon needs to play as "four photons" simultaneously passing through the slit-A, slit-B, slit-C, and slit-D respectively.

The most difficult part is to explain: how does the photon passing through the slit-A interfere with itself passing through the paired slit-B, but not with itself passing through the slit-C or slit-D, to create an interference pattern.

According to the regular wave interpretation, in regular 1D-double-slit experiments, the interfering waves are in the same plane; on the other hand, in 2D-cross-double-slit experiment the interfering waves are in two perpendicular planes. The regular interpretation seems impossible to explain how a photon travels through both the double-slit-AB and the double-slit-CD at the same time and somehow interferes with itself accordingly.

It is a challenge to interpret how a photon "senses": (1) which slit it passes through; (2) which photons it will interfere with, then to create the patterns accordingly.

The above discussions may be applied to all of the cross-double slit experiments.

Experiment-2-7: Tilt cross double slit experiment.

The left of Figure 2.14 shows the experimental setup.

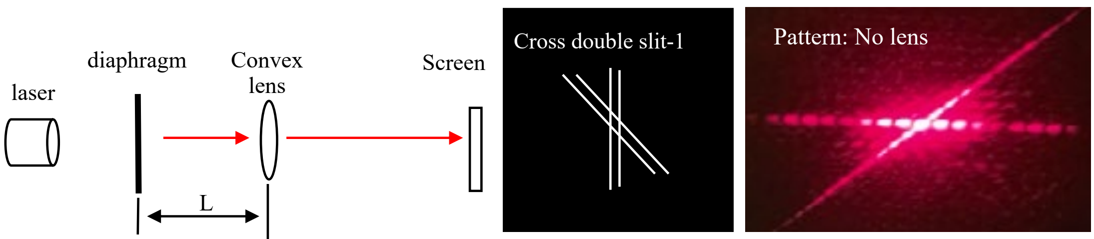


Figure 2.14. Tilt cross double slits and its interference pattern without lens

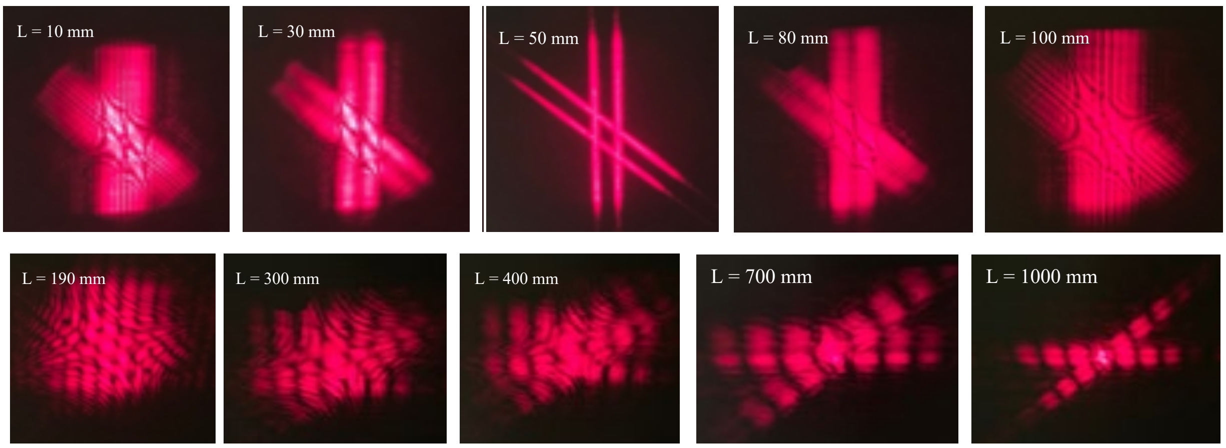


Figure 2.15. Evolution of patterns of tilt cross double slit experiment

Observation: Figure 2.15 shows the evolution of the patterns. When L = 50 mm, the pattern is the typical image of the tilt cross double-slit, which is the non-interference patterns. When L = 100 - 400 mm, we referred the patterns as Transition patterns. The vertical Particle patterns gradually evolve to the orthogonal interference patterns at $L \geq 700$ mm. Approximately, from L = 10 mm to L = 30 mm, the patterns are Pre-Particle patterns, which are more complex than Particle pattern.

Experiment-2-8: Multi-Cross Double slit experiment: the left of Figure 2.16 shows the experimental setup.

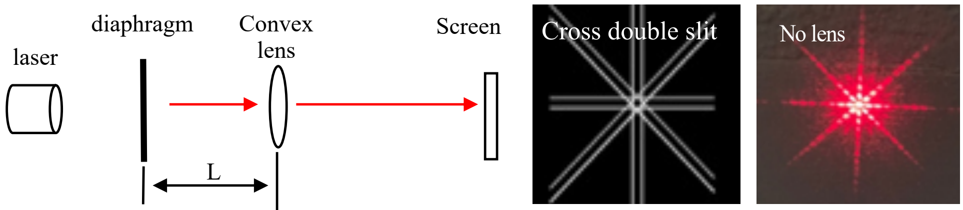


Figure 2.16. Multi-cross double slits and its cross-interference pattern without lens

Figure 2.17 shows the evolution of the patterns

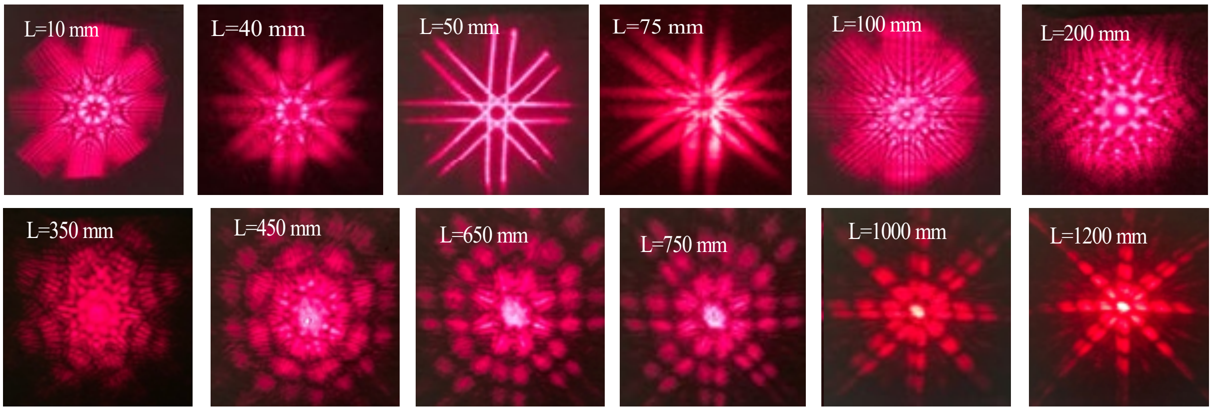


Figure 2.17. Evolution of patterns of multi cross double slit experiment

Observation: From L = 10 mm to L = 40 mm, the patterns are Pre-Particle patterns. When L = 50 mm, the pattern is the typical Particle pattern that is the image of the diaphragm. The Pre Particle patterns gradually evolve to Transition patterns and finally to Interference patterns at $L \geq 1200$ mm

Experiment-2-9: Disc-Ring experiment: Figure 2.18 shows the Experimental setup.

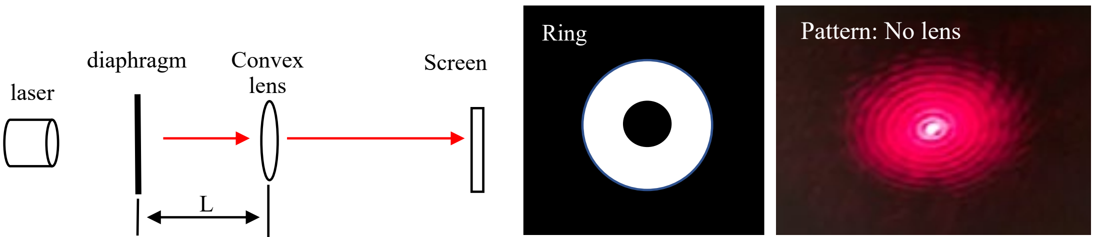


Figure 2.18. Left: experimental setup; Right: Disc ring and its pattern without lens

Figure 2.19 shows the evolution of the patterns

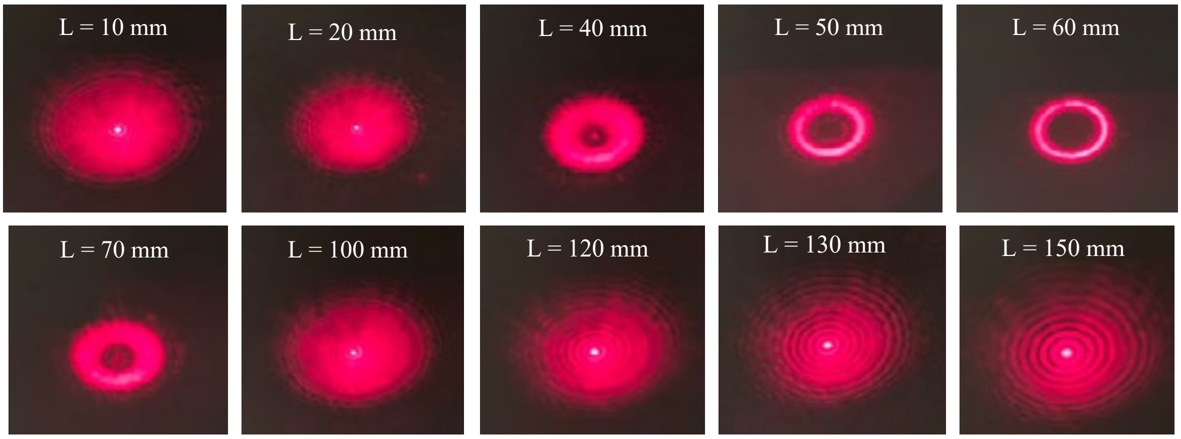


Figure 2.19. Evolution of patterns of disc ring experiment

Observation: When $L = 60$ mm, the pattern is the typical Particle pattern that is the image of the diaphragm of the disc ring. Approximately, from $L = 10$ mm to $L = 40$ mm, the patterns are Pre-Particle patterns.

Experiment-2-10: 1D grating experiment: Figure 2.20 shows the Experimental setup.

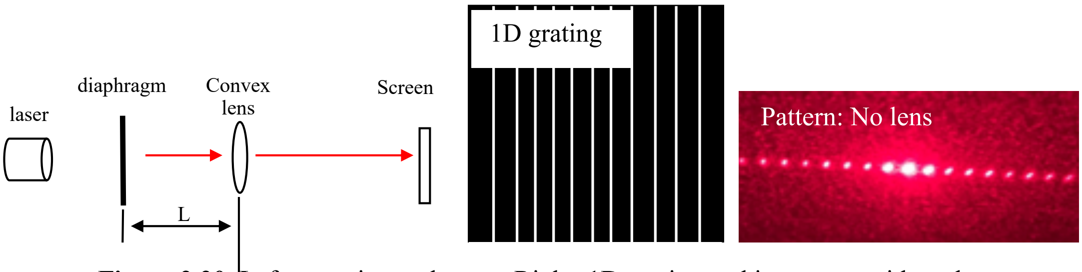


Figure 2.20. Left: experimental setup; Right: 1D grating and its pattern without lens

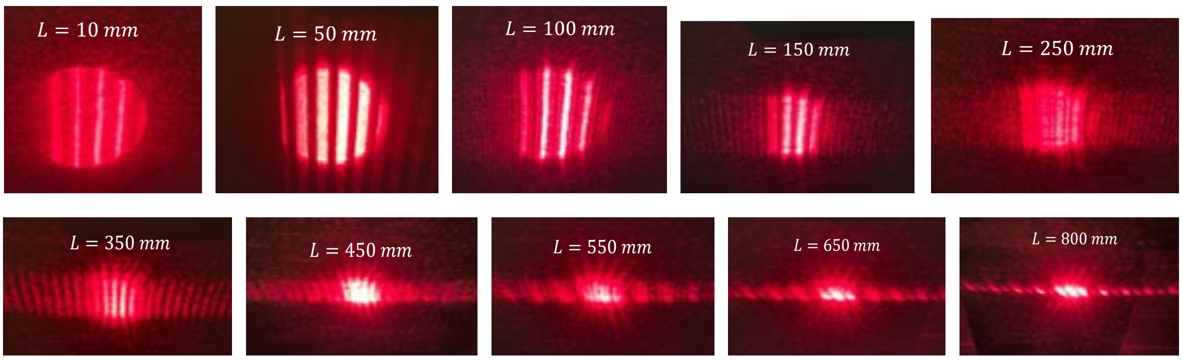


Figure 2.21. Evolution of patterns of 1D grating experiment

Observation (Figure 2.21): at $L = 10$ mm, the pattern is Particle patters. At $L = 50$ mm, the pattern is the typical Particle pattern, the non-interference patter. Then, when $L > 150$ mm, the pattern gradually evolves to the interference pattern. There is no Pre-Particle pattern because all slits are in the same orientation.

Experiment-2-11: 2D grating experiment: Figure 2.22 shows the Experimental setup

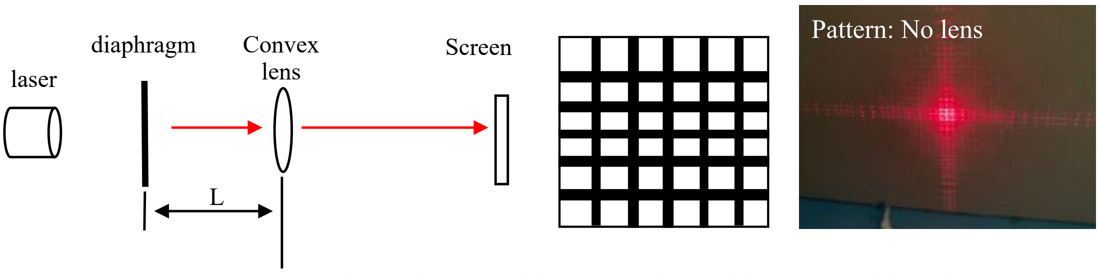


Figure 2.22. Left: experimental setup; Right: 2D grating and its pattern without lens

Observation: Figure 2.23 shows the evolution of the patterns. At L = 10 mm, the patterns are Pre-Particle patterns. The pattern at L = 50 mm is the typical Particle pattern. The pattern gradually evolves to the interference patterns at L = 800 mm.

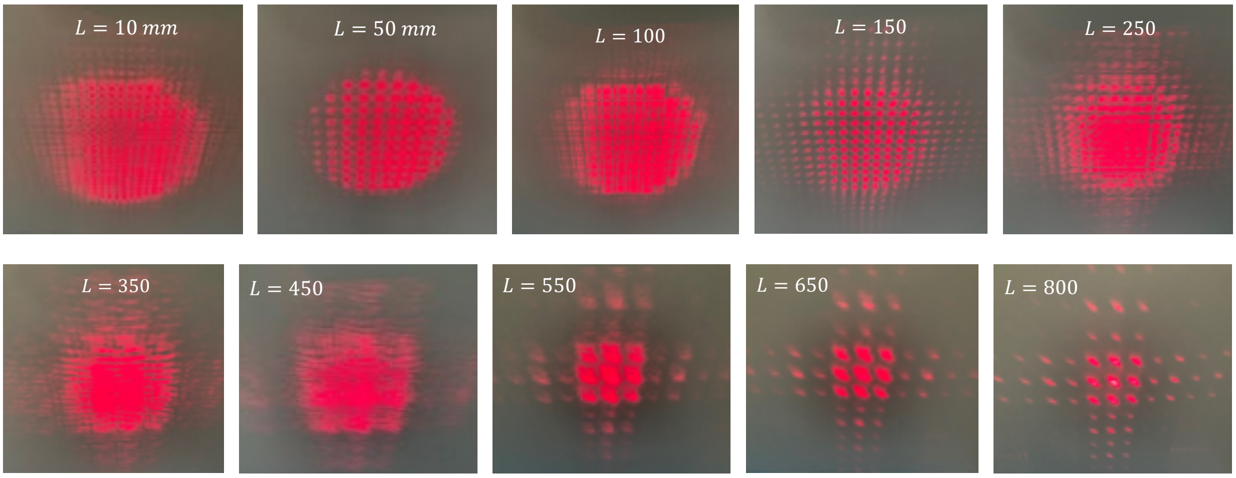


Figure 2.23. Evolution of patterns of 2D grating experiment

2.4.3. Interaction between photons: Patterns superposition

The standard interpretation of the double slit experiment is that the waves pass through the double slit, each slit serves as the secondary source. *After passing two slits and before landing on the screen, two light waves interfere. It is this interfere that causes the interference pattern on the screen.*

Following this line of thinking, taking into account that it is photons passing through the two slits as shown in Experiments-2-1 to Experiment-2-11, we suggest that:

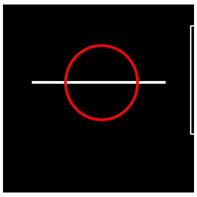
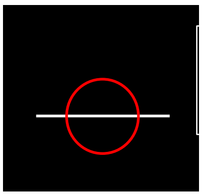
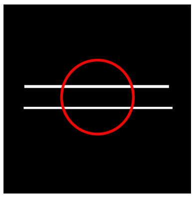
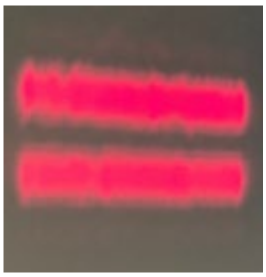
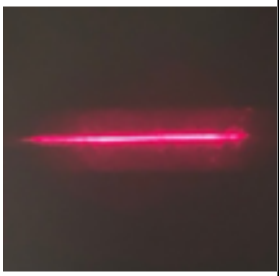
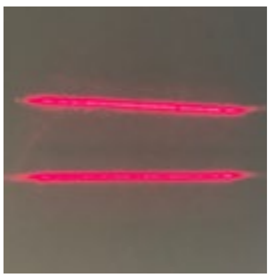
"After passing two slits and before landing on the screen, two beams of photons interact. It is this interaction that causes the interference pattern on the screen".

The "interfere" is the wave terms which is corresponding to the "Interaction" in the physical terms.

To test the suggestion, we consider the following examples

2.4.3.1. Test-1: Two single slits forming a double slit

Let us consider the situation that two single slits form a double slit,

L: mm	Single slit-1 (SS1): pattern-1 (P1)	Single slit-2 (SS2): pattern-2 (P2)	Double slit (DS): pattern-3 (P3)	Remark
	 +	 =		SS1+SS2 = DS The red circle is the spot of the laser beam shining on the diaphragms.
10				P1+P2 = P3 P1, P2 and P3 are Particle patterns and in the same direction of the slits. The lengths of Particle patterns are the diameter of laser beam.
50				P1+P2 = P3 P1, P2 and P3 are Particle patterns and in the same direction of the slits

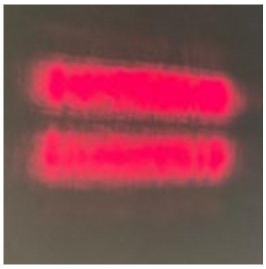
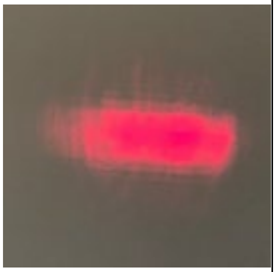
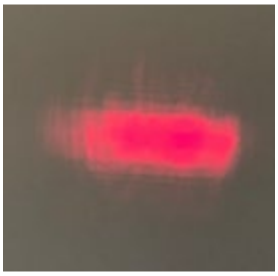
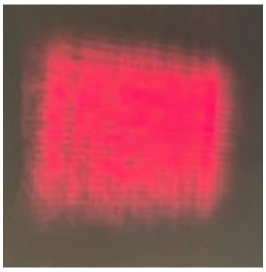
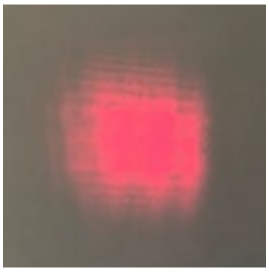
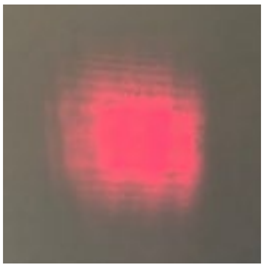
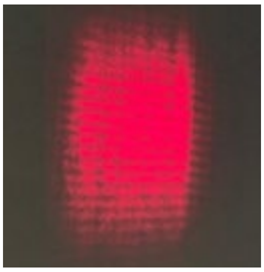
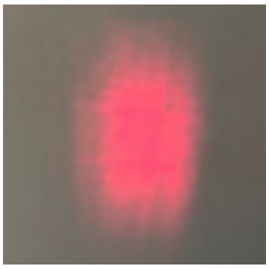
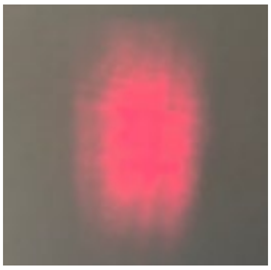
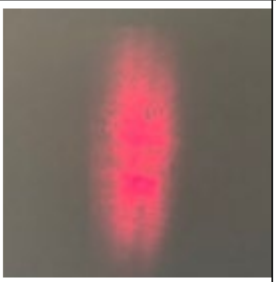
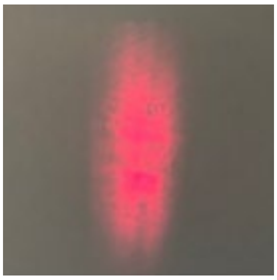
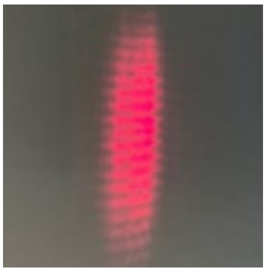
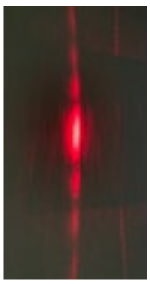
100				P1+P2 = P3 P1, P2 and P3 are Particle patterns, and shrink in horizontal deriction and expand in vertical deriction.
150				P1+P2 ≠ P3 P1, P2 and P3 are Transition patterns, and shrink in horizontal deriction and expand in vertical deriction.
300				P1+P2 ≠ P3 P1, P2 and P3 are Transition patterns, and shrink in horizontal deriction and expand in vertical deriction. P3 shows the interference feature.
450				P1+P2 ≠ P3 P1, P2 and P3 are Transition patterns, and shrink in horizontal deriction and expand in vertical deriction. P3 shows the interference feature.
650				P1+P2 ≠ P3 P1, P2 and P3 are Transition patterns, and shrink in horizontal deriction and expand in vertical deriction. P3 shows the interference
				feature.
1100/ 1000				P1+P2 ≠ P3 P1, P2 and P3 are orthogonal to the slits. P3 is the interference pattern. P1 and P2 are diffraction patterns.

Table 2.1. Patterns evolution of two single slits forming a double slit

Above patterns show:

(1) Photons pass through the single slit-1 (SS-1) produce the pattern-1 (P1); Photons pass through the single slit-2 (SS-2) produce the pattern-2 (P2); Photons pass through the double slit (DS) produce the pattern-3 (P3).

(2) L = 10 – 100 mm: At the macroscopic distance "L", 10 – 100 mm, SS-1, SS-2 and DS produce Particle patterns P1, P2 and P3 respectively; P3 is the combination of P1 and P2. The Particle patterns P1, P2 and P3 are produced attributing to the interactions *between photons and SS-1, SS-2 and DS* respectively.

(3) L = 150 – 800 mm: we observe Transition patterns, P1, P2, and P3, respectively; P3 is NOT the combination P1 and P2. We suggest that Transition patterns P1, P2 and P3 are produced attributing to the ***interactions between photons***.

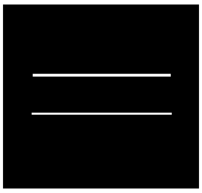
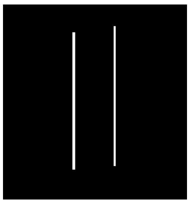
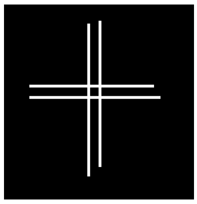
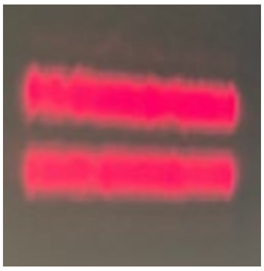
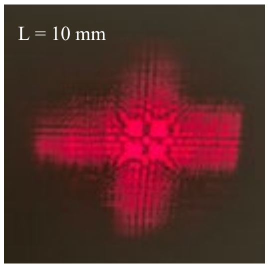
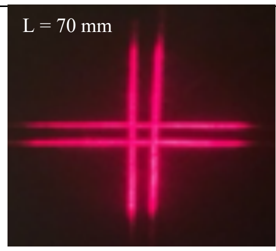
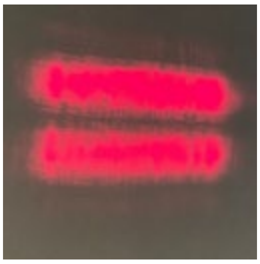
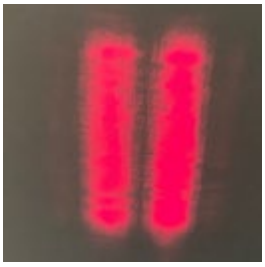
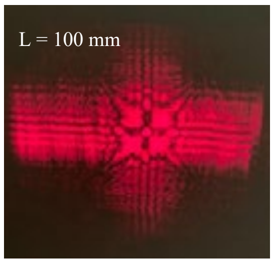
(4) L ≥ 1000/1100 mm: we observe the Diffraction patterns, P1 and P2, and the Interference pattern P3, respectively; P3 is NOT the combination P1 and P2.

(5) New Mystery: Particle patterns evolving to orthogonal diffraction/interference patterns.

(6) We suggest that the patterns, P1, P2 and P3, are produced attributing to both ***the interactions between photons and SS-1, SS-2 and DS respectively, and between photons especially for Transition pattern at L = 150 to L=1100***.

2.4.3.2. Test-2: Two double slits forming a cross-double slit

Let us consider the situation that two double slits form a cross double slit,

L: mm	Double slit-1 (DS1) pattern-1 (P1)	Double slit-2 (DS2) pattern-2 (P2)	Cross Double slit (CDS) pattern-3 (P3)	Remark
	 +	 =		DS1+DS2 = CDS
10				P1+P2 ≠ P3 P3 is pre-Particle patterns produced due to interactions between photons and DS1, DS2, CDS, respectively
50/70				P1+P2 = P3 P1, P2 and P3 are Particle patterns and produced due to the interaction between photons and DS1, DS2, CDS, respectively
100				P1+P2 ≠ P3

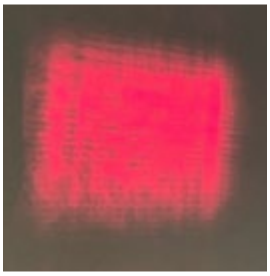
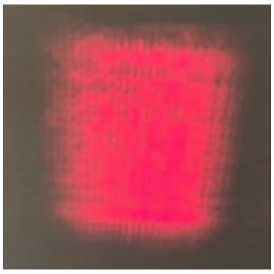
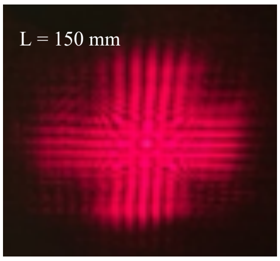
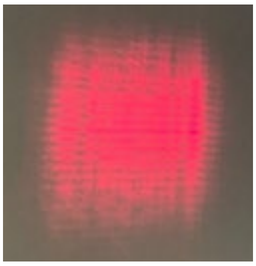
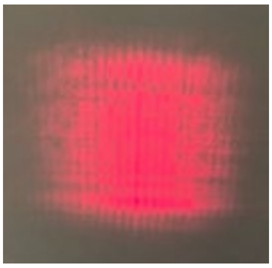
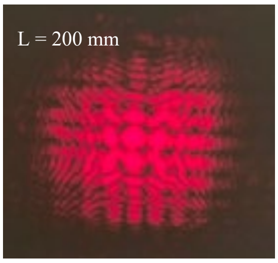
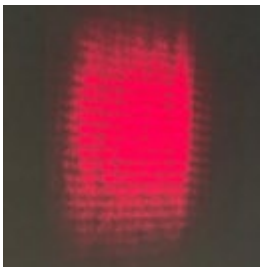
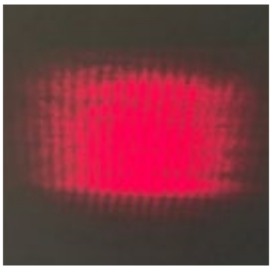
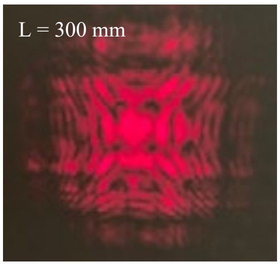
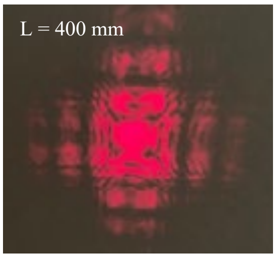
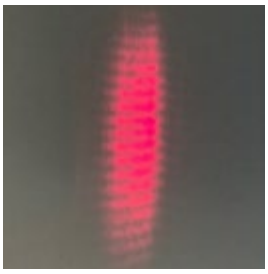
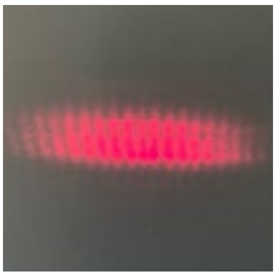
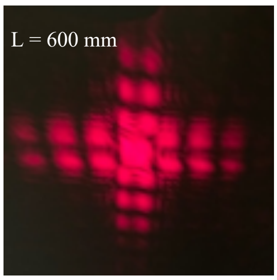
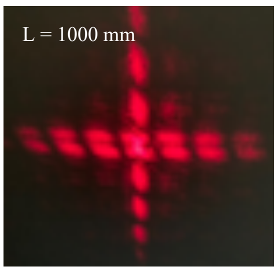
150				P1+P2 ≠ P3
200				P1+P2 ≠ P3
300				P1+P2 ≠ P3
450/ 400				P1+P2 ≠ P3
650/ 600				P1+P2 ≠ P3
1100/ 1000				P1+P2 = P3

Table 2.2: Patterns evolution of two single slits forming a double slit

We suggest that the patterns, P3 are produced attributing to both ***interactions between photons and DS-1, DS-2 and CDS respectively, and between photons especially for Pre-Particle pattern at L = 10 mm and for Transition*** pattern at L = 100 to L=800 mm.

2.5. Summary:

The phenomena of Experiment-2-1 to Experiment-2-11 are consistent. The phenomena of the noninterference patterns evolving to the interference patterns is universal.

Challenges are:

(1) to interpret consistently the evolution phenomena;

(2) there is a phenomenon that: for a double slit and a 1D grating, for which all slits are in the same orientation, there is no Pre-Particle pattern; however, for tilt cross double slit, multi-cross double slit and 2D grating, for which the slits are in different orientations, there are Pre-Particle patterns, which is complex to interpret.

We show the phenomena for theoretically restudying the nature of the light and the concepts of both coherence/incoherence and wave function collapse.

This fundamental phenomenon can be utilized to study the nature of the light and to certain applications.

3. Non-Diffraction pattern evolving to Diffraction pattern

The double slit has been extended to the cross double slits that have much more variations [6]. In Section 2, we show the universal phenomena that, the nature and the characteristics of the patterns depend on distance from the double slit/cross double slit, e.g., in Zone-1, Zone-2 and Zone-3, the patterns are Particle patterns, Transition patterns and Interference patterns, respectively. Namely, in the same classical experiment, the non-interference patterns evolve to the interference patterns [7].

In this Section, we first extend the single slit to the cross single slits that have much more variations, and then, show the phenomena of the non-diffraction patterns evolving to the diffraction patterns [8].

3.1. Single slit to Cross-Single-Slit

First let us extend the single slit to the cross single slit. Thus, we have variety of configurations of the shingle slit crossing single slit, and the single slit crossing double slit, etc., as shown in Figure 3.1.

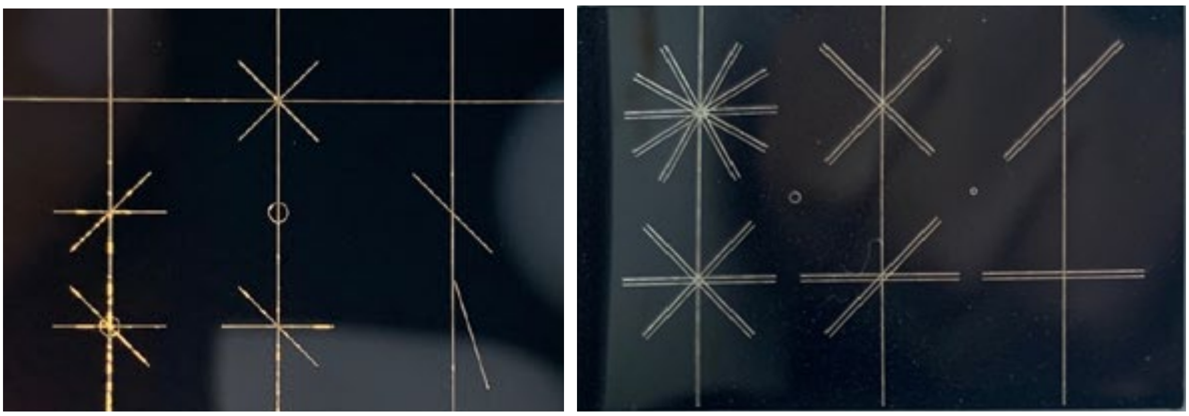


Figure 3.1 Diaphragms of single slit crossing single slit and single slit crossing double slit

3.2. Experiments with lens

Experimental setup

We use the same experimental setup for all experiments in Section 3, with different diaphragms and placing the lens at different locations between the diaphragm and the screen (Figure 3.2).

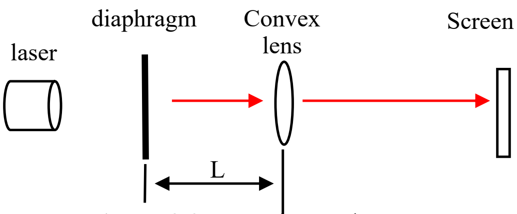


Figure 3.2. Experimental setup

Experiment-3-1: Single slit experiment: Figure 3.3 shows the standard single slit and its diffraction pattern.

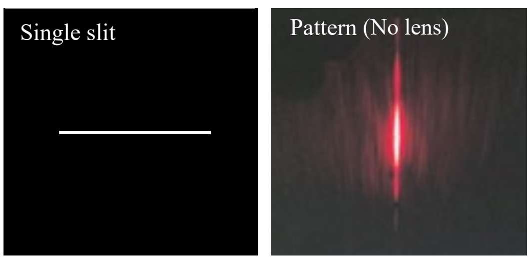


Figure 3.3. Single slit and its pattern without lens

Figure 3.4 shows the patterns evolution when the lens is placed at the distant L from the single slit. The L changes from 10 mm to 1000 mm.

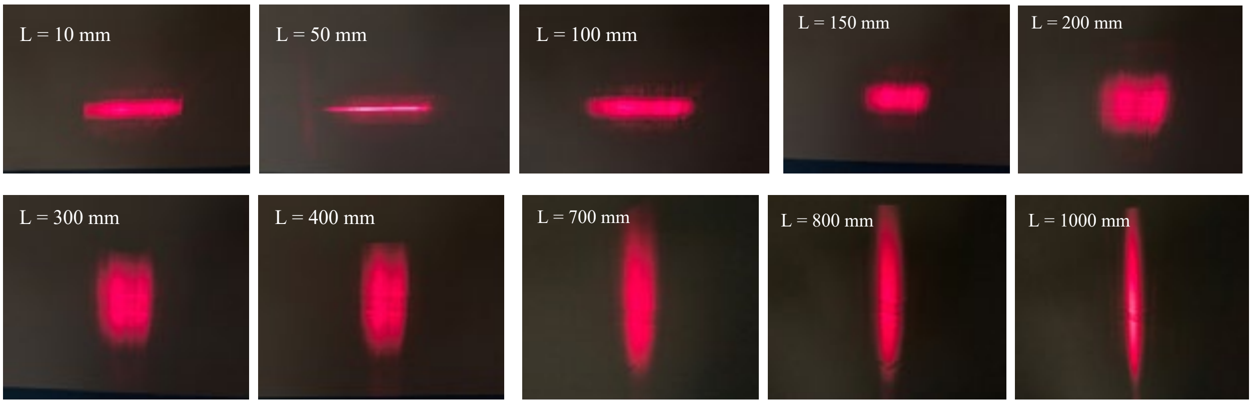
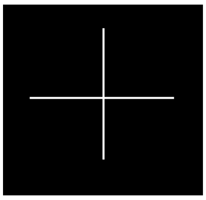
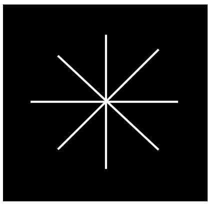
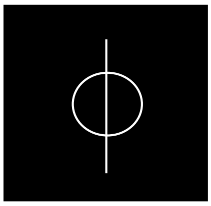
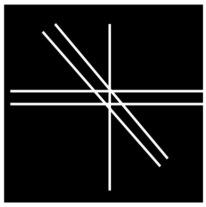
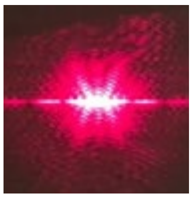
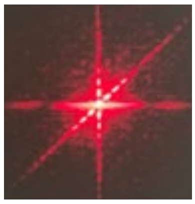
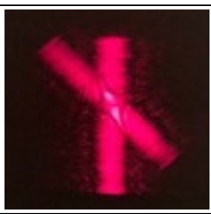
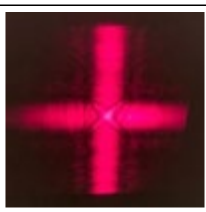
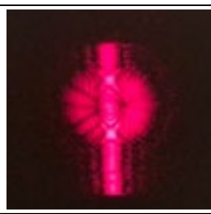
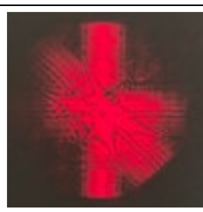
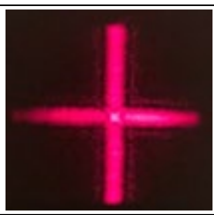
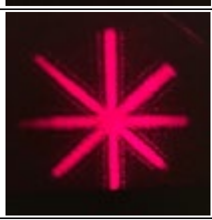


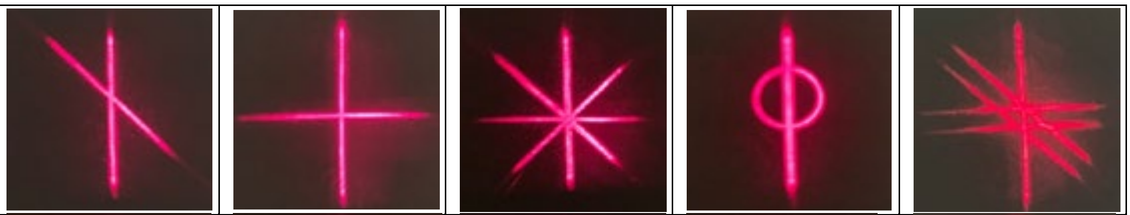
Figure 3.4. Evolution of pattern of single slit experiment

Observation: We observe the evolution of the patterns. Namely, the patterns are distance-dependent. Figure 3.2 shows the cross-section views of the evolution of the patterns, which show how the horizontal non-diffraction patter (start from L = 10 mm) evolves to the orthogonal diffraction pattern at ($L \geq 1000\ mm$). The pattern at L = 50 mm is typical Particle pattern which is the image of the single slit. Between $L = 150\ mm - 700\ mm$, we call the patterns "Transition pattern". When $L > 700\ mm$, the patterns evolve to the typical vertical diffraction patterns

Experiment-3-2: Tilt single slit crossing single slit
Experiment-3-3: Single slit orthogonally crossing single slit
Experiment-3-4: Four Single slits crossing at the same point
Experiment-3-5: Single slit crossing ring
Experiment-3-6: Single slit crossing two double slits

The evolution of non-diffracting pattern to the diffraction patterns of Experiment-3-2 to Experiment-3-6 are summarized in Table 3.1. (0*: indicates the diffraction patterns at far field when there is no lens used).

L: mm	Tilt single slit crossing single slit 	Single slit crossing single slit 	4 single slits crossing 	Single slit crossing Ring 	Single slit cross double slit 
0*					
10					
30					

50	
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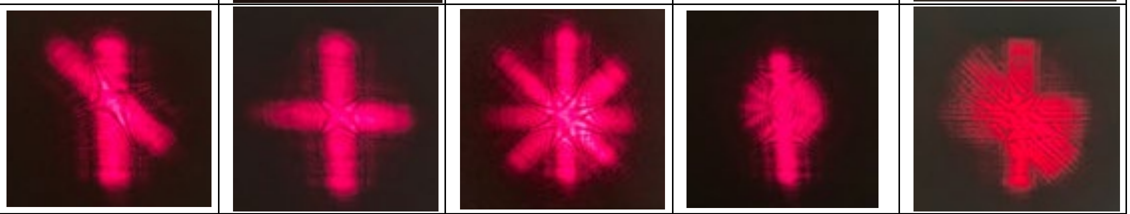
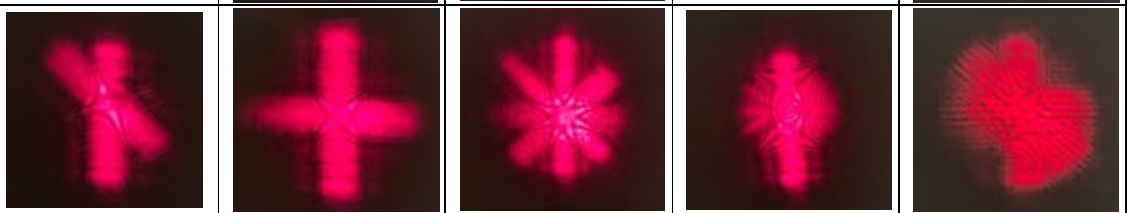
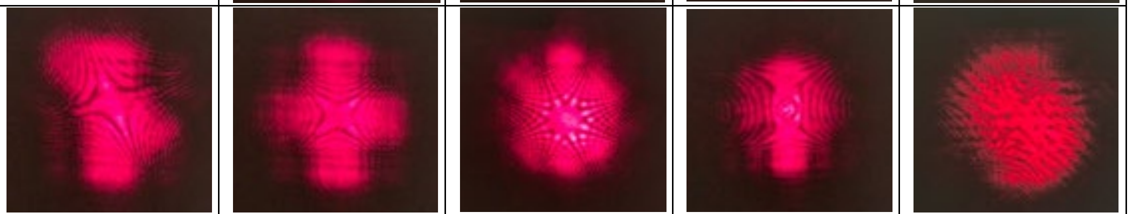
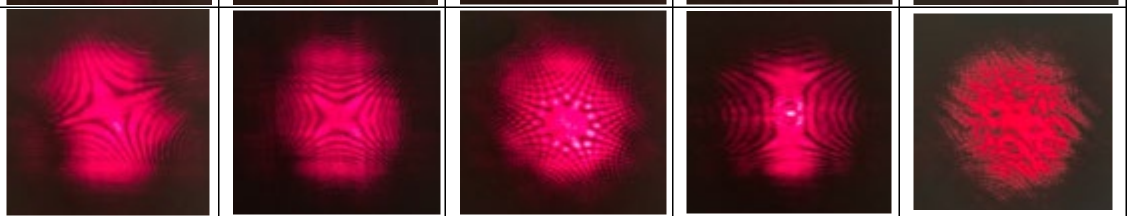
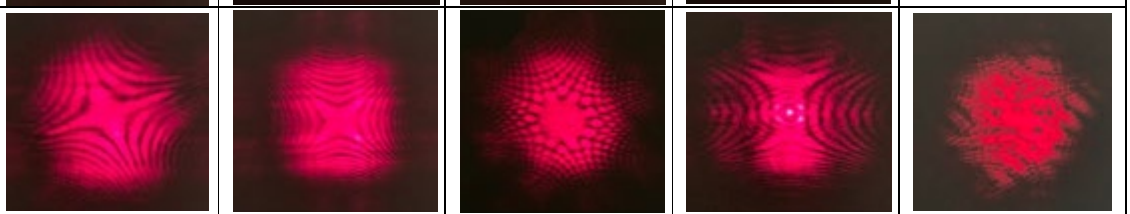
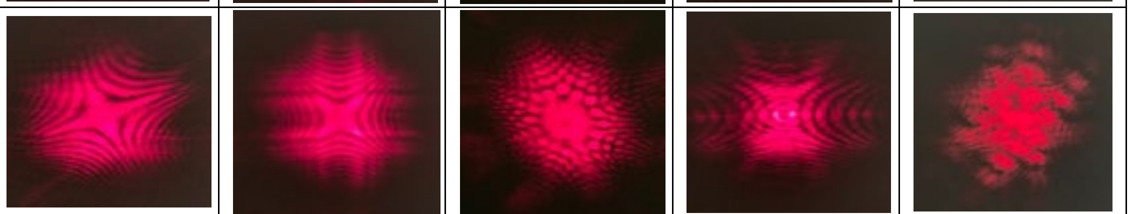
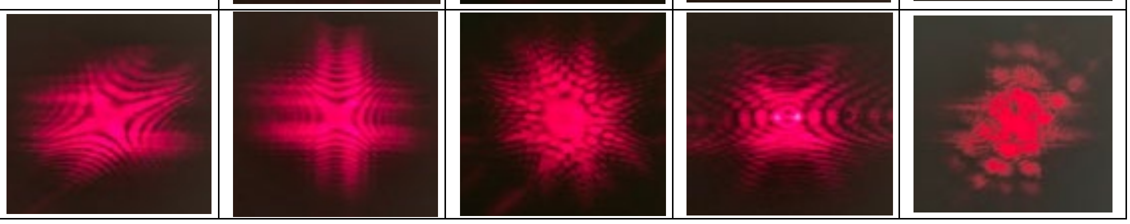
100	
110	
150	
200	
250	
350	
450	

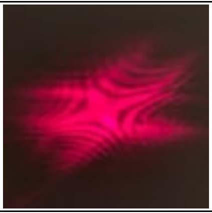
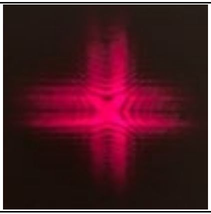
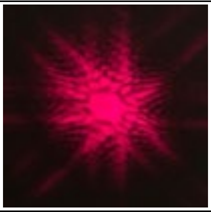
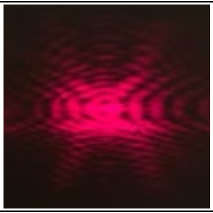
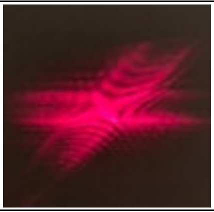
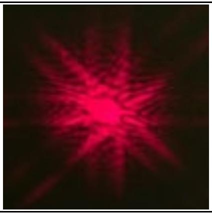
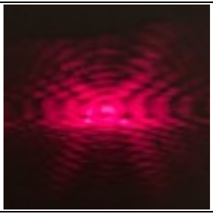
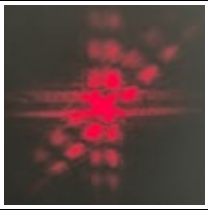
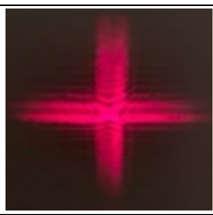
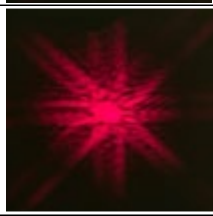
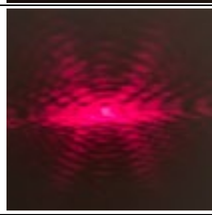
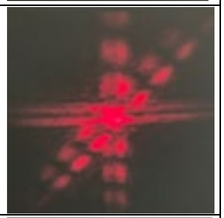
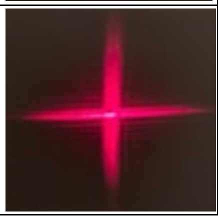
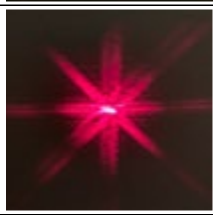
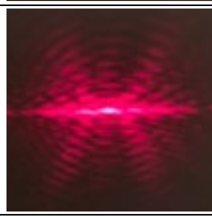
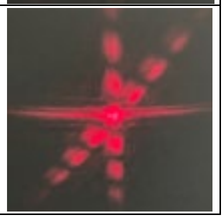
550					
650					
800					
1100					

Table 3.1. Evolution of patterns of cross dingle slit experiments

Observation: for all of Experiments

(1) At L = 10 mm, the patterns are Pre-particle patterns

(2) At L = 50 mm, the patterns are Particle patterns

(3) At L = 80 to 800 mm, the patterns are Transition patterns

(4) At L = 1100 and larger, the patterns are Diffraction/ Interference patterns

Note: (1) the evolution is gradually taking place, there is no clear cut between Particle patterns and Transition patterns, and between Transition patterns and the Diffraction patterns.

3.3. Summary

In this Section, we

(1) proposed the cross single slit.

(2) show the patterns evolution from the non-diffraction patterns to the diffraction patterns.

(3) the two evolutions taking place in the same experiments (e.g., Experiment-6): The non-diffraction patterns evolving to the diffraction patterns, and the non-interference patterns evolving to the interference patterns.

The consistent and complete physical/mathematical interpretations are required.

4. Interference-Diffraction hybrid pattern

4.1. Two non-parallel single slits producing Interference-Diffraction hybrid pattern

4.1.1. Experimental setup

In the following experiments, we use the same experiment setup of Figure 4.1:

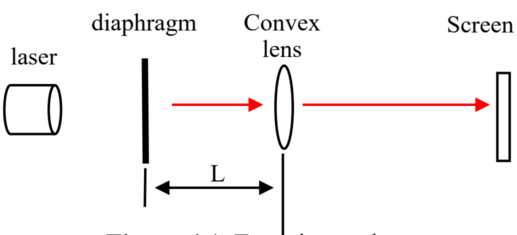


Figure 4.1. Experimental setup

4.1.2. Experiments

Experiment-4-1: The angle between two slits is 17.50 (Figure 4.2: left). The experiment contains two steps.

First step: utilizing the experiment setup in Figure 4.1 without lens. Figure 4.2 shows the novel Interference- Diffraction hybrid pattern.

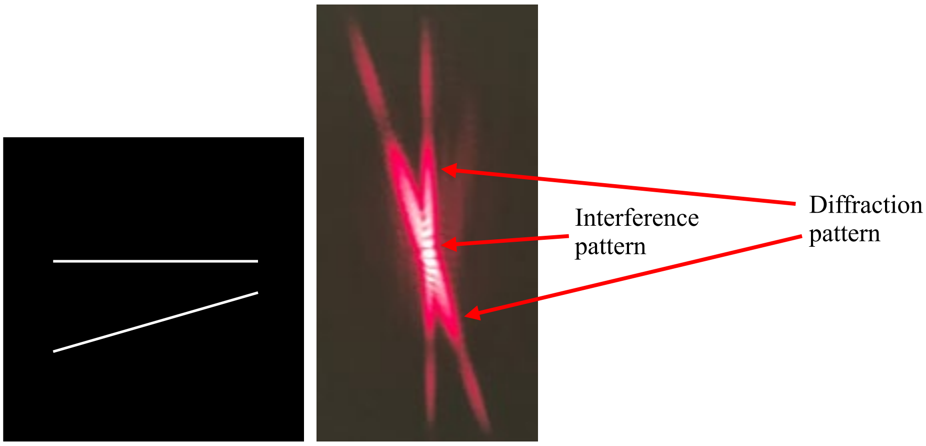
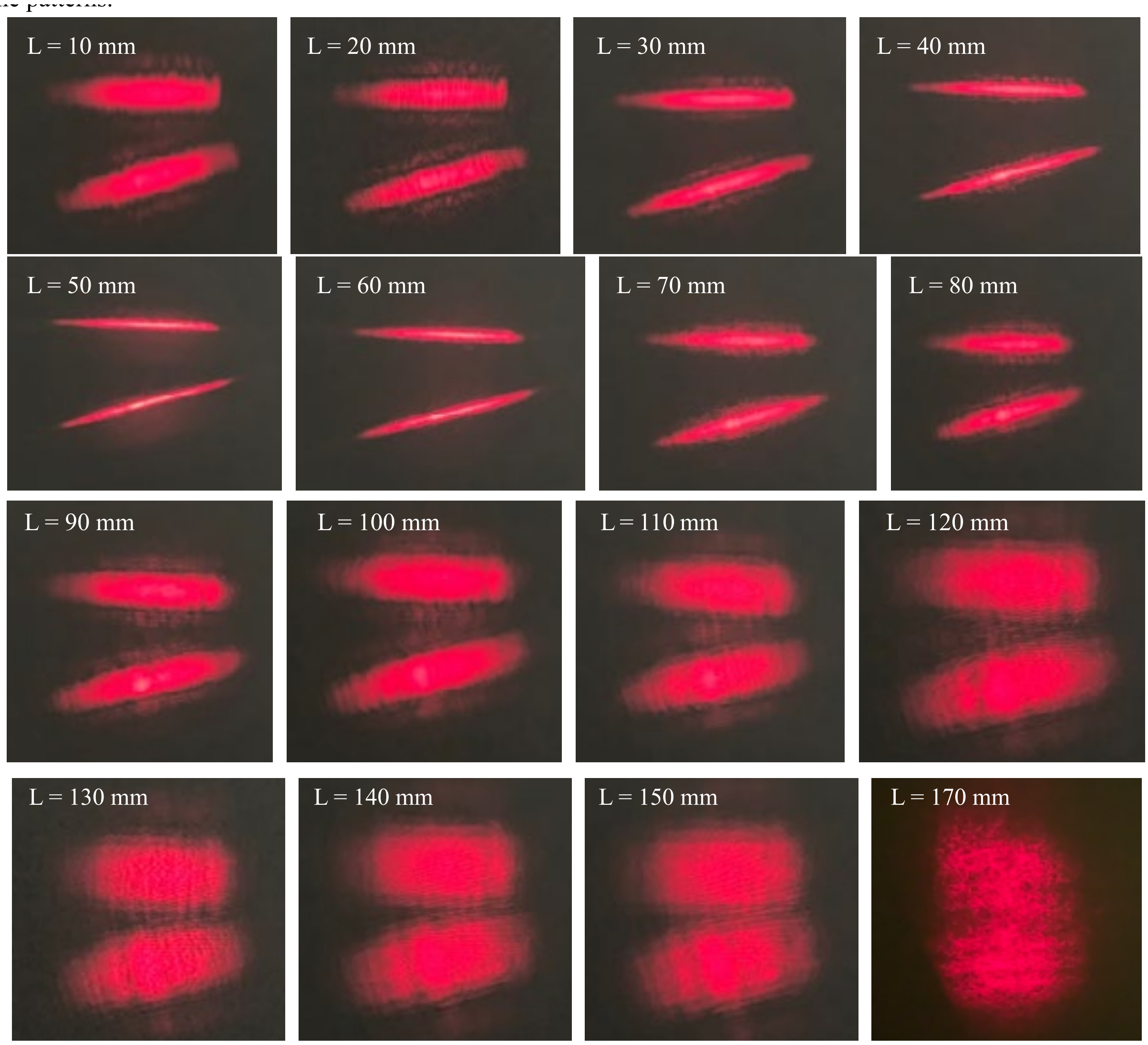


Figure 4.2. Novel pattern: interference pattern embedded in two diffraction patterns

Observation: The interference pattern is embedded in the two diffraction patterns; we referred the pattern as the Interference pattern + diffraction hybrid pattern or "Hybrid pattern". Two slits produce two diffraction patterns respectively as they were independent single slit. While two slits produce the interference pattern as they are forming the double slit.

The mysterious phenomenon is that the interference pattern is embedded in the two diffraction patterns [9].

Second step: to study how the hybrid pattern is produced, let us study the pattern evolution by utilizing the experiment setup in Figure 4.1 with the lens between the diaphragm and the screen, i.e., the distance-dependence of the patterns.



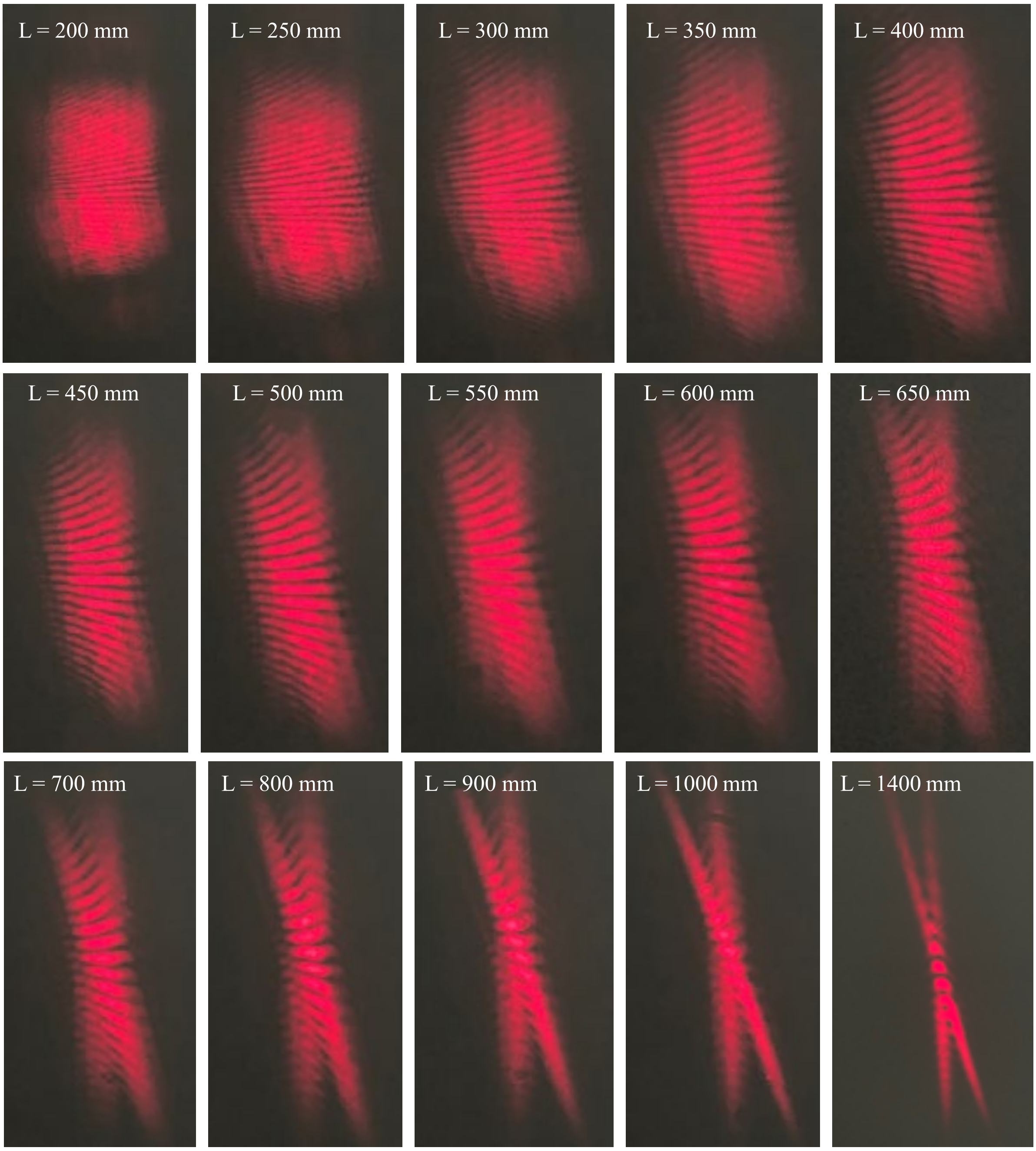
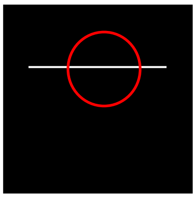
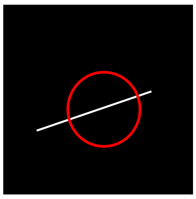
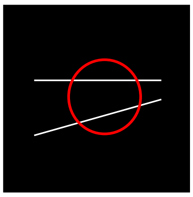
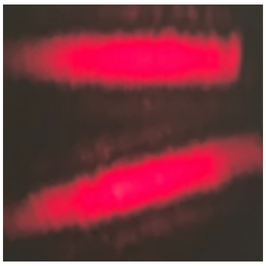
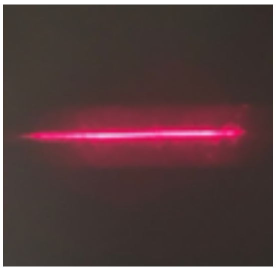
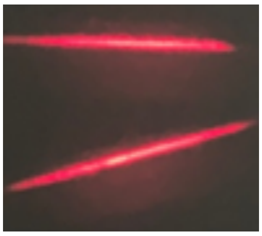
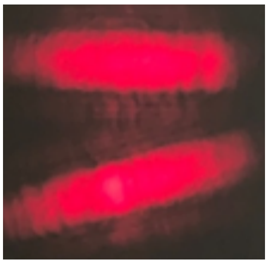
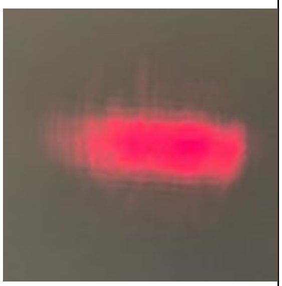
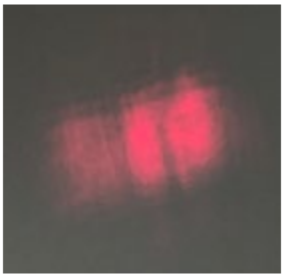
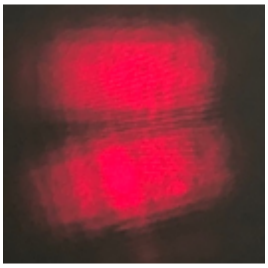
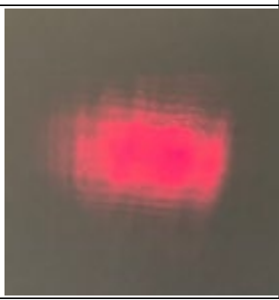
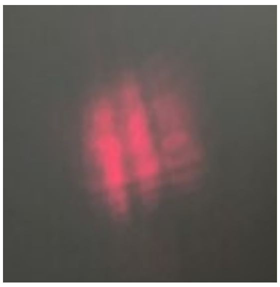
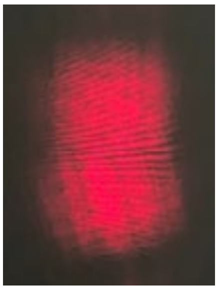


Figure 4.3. Pattern evolution: from Particle Patterns to Interference + Diffraction Hybrid Patterns

Observation: Figure 4.3 shows the pattern evolution. The patterns are the Particle patterns, at $L = 10 - 100$ mm. At $L = 150 - 1000$ mm, we call the patterns Transition patterns. At $L \geq 1400$ mm, the patterns are the Interference + Diffraction Hybrid Patterns.

4.2. Interaction between photons: non-parallel-two-slit

The observations are summarized in Table 4.1.

L: mm	Single slit-1 (SS1): pattern-1 (P1)	Single slit-2 (SS2): pattern-2 (P2)	Non-parallel two slit (NTS): pattern-3 (P3)	Remark
	 +	 =		SS1+SS2 = NTS The red circle is the spot of the laser beam shining on the diaphragms.
10				P1+P2 = P3 P1, P2 and P3 are Particle patterns and in the same direction as the slits. The lengths of Particle patterns are the diameter of laser beam.
50				P1+P2 = P3 P1, P2 and P3 are Particle patterns and in the same direction as the slits. The lengths of Particle patterns are the diameter of laser beam.
100				P1+P2 = P3 P1, P2 and P3 are Particle patterns and in the same direction as the slits. The length of patterns becomes shorter and the width becomes wider.
150				P1+P2 $\approx$ P3 P1, P2 and P3 are Particle patterns and in the same direction as the slits. The length of Particle patterns becomes shorter and the width becomes wider.
200				P1+P2 $\neq$ P3 P1, P2 and P3 are Transition patterns. The length of Transition patterns becomes shorter and the width becomes wider.

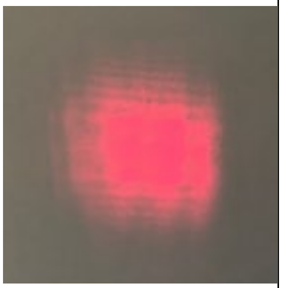
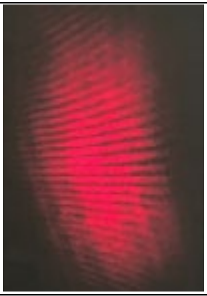
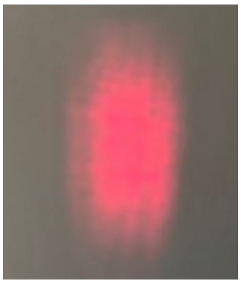
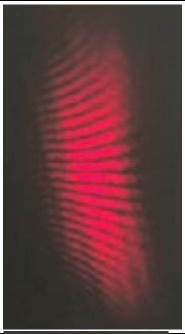
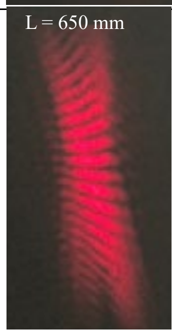
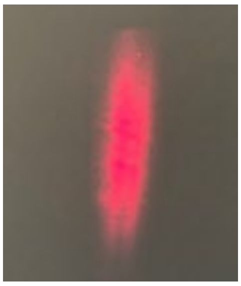
300				P1+P2 ≠ P3 P1, P2 and P3 are Transition patterns. The length of Transition patterns becomes shorter and the width becomes wider.
450				P1+P2 ≠ P3 P1, P2 and P3 are Transition patterns. The length of Transition patterns becomes shorter and the width becomes wider.
650				P1+P2 ≠ P3 P1, P2 and P3 are Transition patterns. The length of Transition patterns becomes shorter and shorter and the width becomes wider and wider.
800				P1+P2 ≠ P3 P1, P2 and P3 are Transition patterns. The length of Transition patterns becomes shorter and shorter and the width becomes wider and wider.
1100/ 1000				P1+P2 ≠ P3 P1 and P2 are diffraction patterns. P3 is Hybrid pattern.

Table 4.1. Patterns of non-parallel two slit

Observation: start from L = 150 mm, two separated patterns of P3 start to combine, and continuously evolve. We suggest that the evolution of P3 shows the effect of the interactions between photons.

4.3. Interference pattern to hybrid pattern to diffraction pattern: parallel double slit to non-parallel-two-slit

The interference phenomena and the diffraction phenomena are two basic phenomena in physical optics. The standard interpretation of the double slit experiment is that before and after passing through the double slit diaphragm, the light behaves as waves, either the optical waves, or the Electromagnetic waves, or the probability waves, and the patterns are interference. The two slits are parallel. Experiment-4-1 shows that, when the two slits are not parallel, the pattern is the hybrid pattern, i.e., the partial interference pattern is embedded in the diffraction patterns.

Next, we show the phenomena: when the angle between two slits increases from the 0^0 to 45^0, the interference pattern becomes the partial interference + diffraction hybrid patterns and, finally, become the crossing diffraction patterns. In the two non-parallel-slits experiment, the nature and the characteristics of the patterns depend not only on the distance from the diaphragm, but also on the angle between two slits.

4.3.1. Diaphragm of non-parallel-two-slits

Now, we study the non-parallel two slits. For this purpose, we utilize the diaphragm containing 16 two-slits with different angles: 0^0 - 45^0 (Figure 4.4).

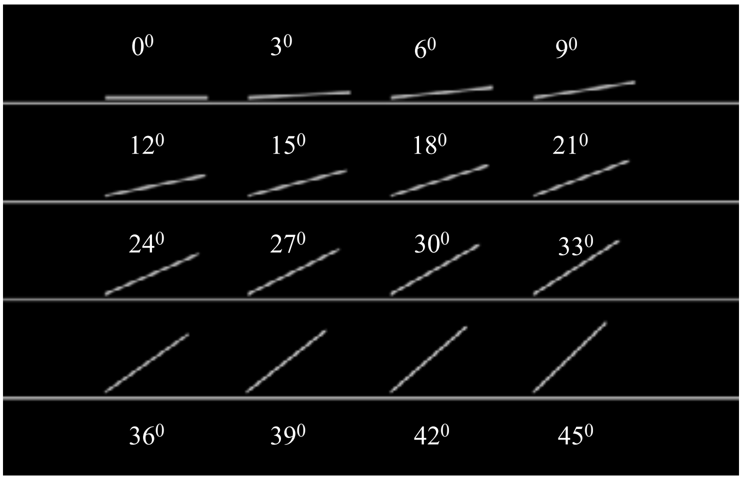


Figure 4.4. Diaphragm of parallel two-slits and non-parallel two-slits with angles: 0^0 - 45^0

The all distances between the bottom-end of each tilt short slit and the horizontal long slits are 0.3 mm.

4.3.2. Experiments: patterns of two-slits experiments depending on angle between two slits

Experiment setup

The same experiment setup (Figure 4.5 and Figure 4.6) is for Experiment-2 to Experiment-17. We set the distance between the diaphragm and the screen 1400 mm.

Figure 4.5. Experiment setup

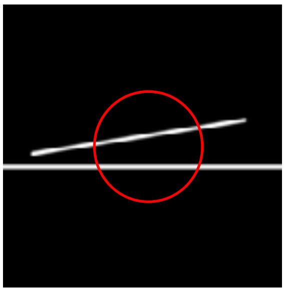


Figure 4.6. Spot of laser at non-parallel two-slits

The laser with beam-diameter 3 mm aims at the non-parallel two-slits, as shown by the red circle in Figure 4.6.

Experiment-4-2: 0^0 between two slits:

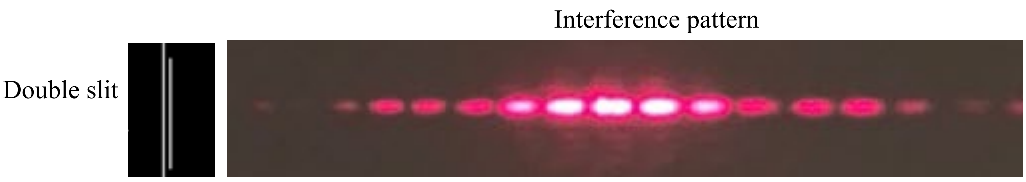


Figure 4.7. Standard double slit experiment and interference pattern

Observation: the parallel-two-slit (the normal double slit) produces the interference pattern, which can be interpreted by all three standard wave theories. Figure 4.7 clearly shows the fringes $m = \pm 6$.

Experiment-4-3: 3⁰ between two slits:
In this experiment, the angle between two slits is 3^0.

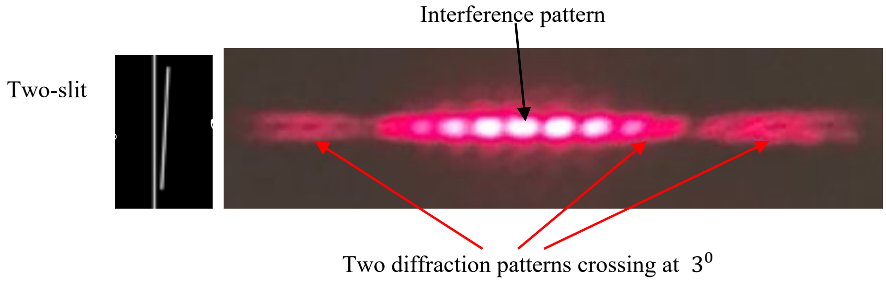


Figure 4.8. Non-parallel two-slit (crossing at ^{30}) experiment and hybrid pattern

Observation: we observe the hybrid pattern, i.e., the partial interference pattern embedded in the diffraction patterns. Two diffraction patterns are barely distinguishable. The partial interference pattern shows $m = \pm 3$ fringes.

The nature and characteristic of the pattern is sensitive to the angle between two slits.
It is challenge to interpret the hybrid patten by the wave theories.

Experiment-4-4: 6⁰ between two-slits:
In this experiment, the angle between two slits is 6^0.

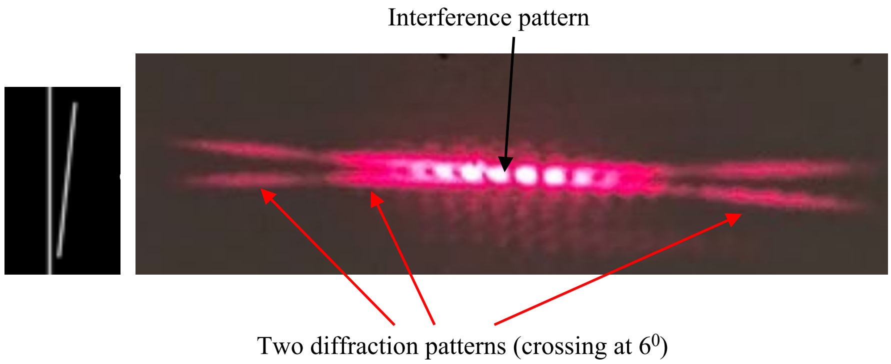


Figure 4.9. Non-parallel two-slit (crossing at 6^0) experiment and hybrid pattern

Observation: we observe the hybrid pattern. The two diffraction patterns are clearly distinguishable. The partial interference pattern shows $m = \pm 3$.

Experiment-4-5: 9⁰ between two slits:
In this experiment, the angle between two slits is 9^0.

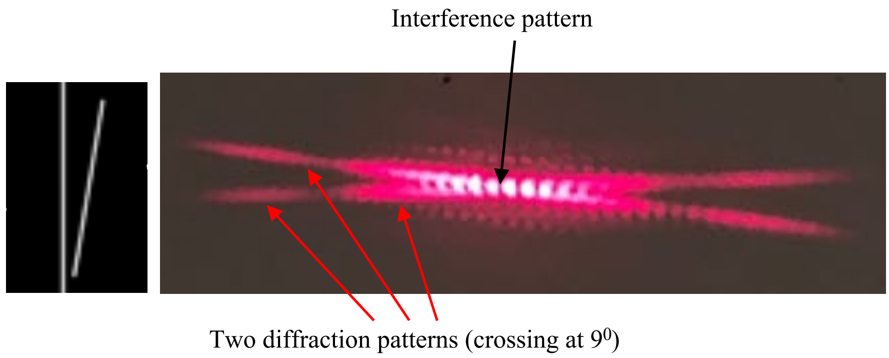


Figure 4.10. Non-parallel two-slit (crossing at 9^0) experiment and hybrid pattern

Observation: we observe the hybrid pattern. The interference pattern is embedded in two diffraction patterns.

Experiment-4-6: 12⁰ between two slits:
In this experiment, the angle between two slits is 12^0.

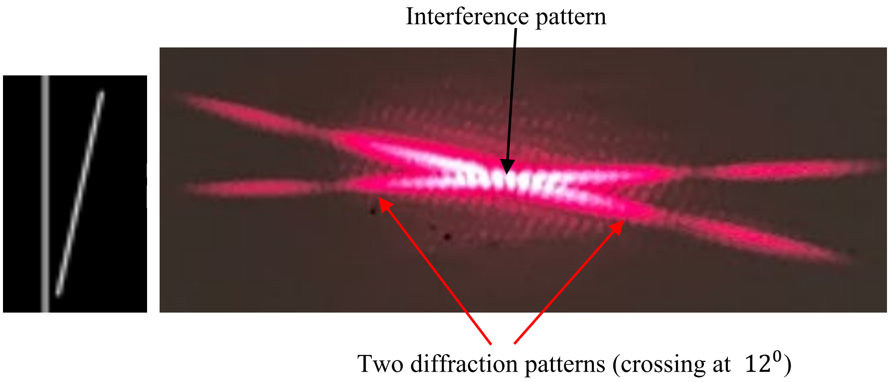


Figure 4.11. Non-parallel two-slit (crossing at 12^0) experiment and hybrid patter

Observation: we observe the hybrid pattern.

Experiment-4-7: 15^0 between two slits:

In this experiment, the angle between two slits is 15^0.

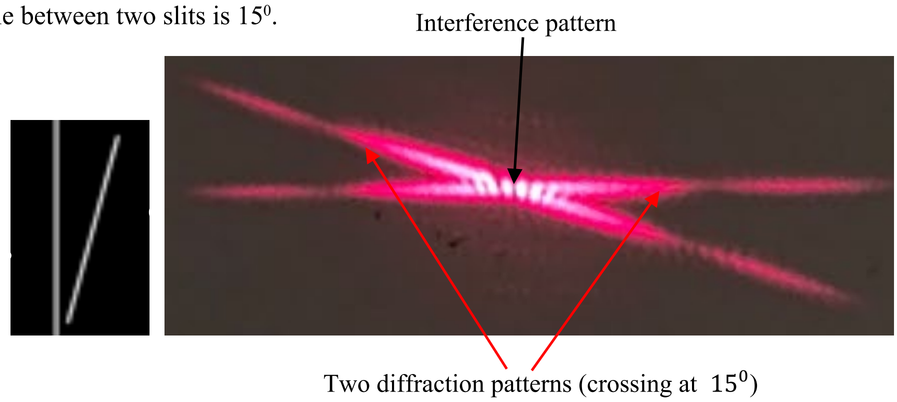


Figure 4.12. Non-parallel two-slit (crossing at 15^0) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-4-8: 18^0 between two slits:

In this experiment, the angle between two slits is 18^0.

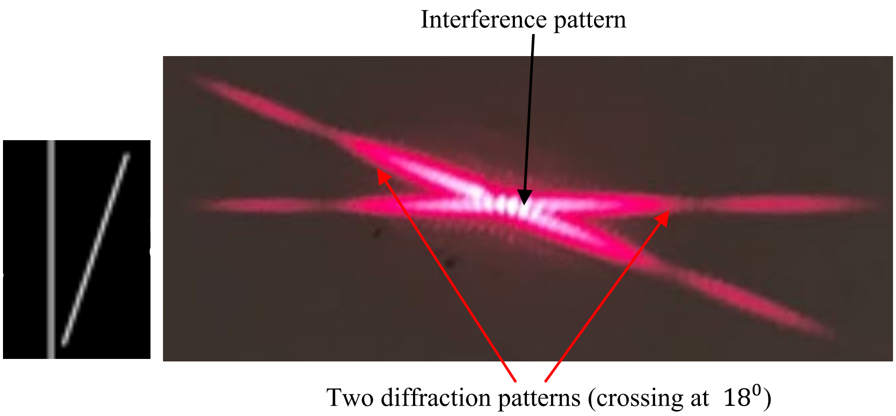


Figure 4.13. Non-parallel two-slit (crossing at 18^0) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-4-9: 21^0 between two slits:

In this experiment, the angle between two slits is 21^0.

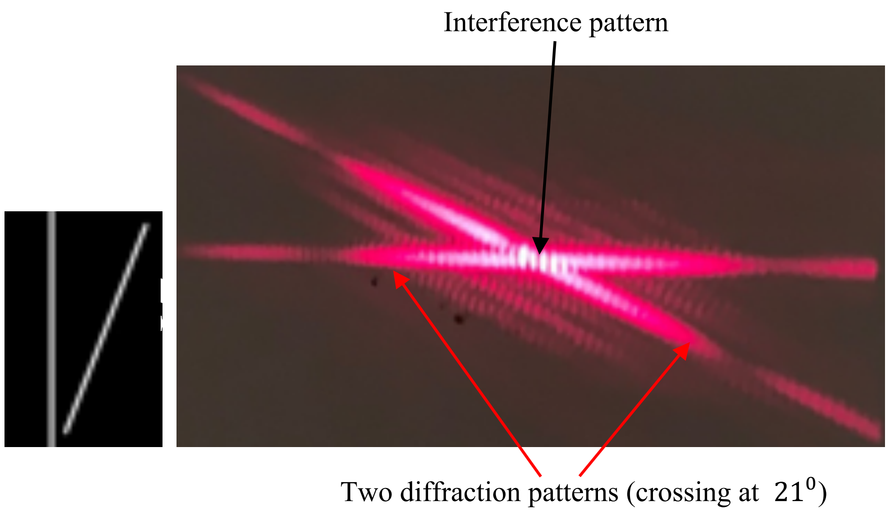


Figure 4.14. Non-parallel two-slit (crossing at 21^0) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-4-10: 24^0 between two slits:
In this experiment, the angle between two slits is 24^0.

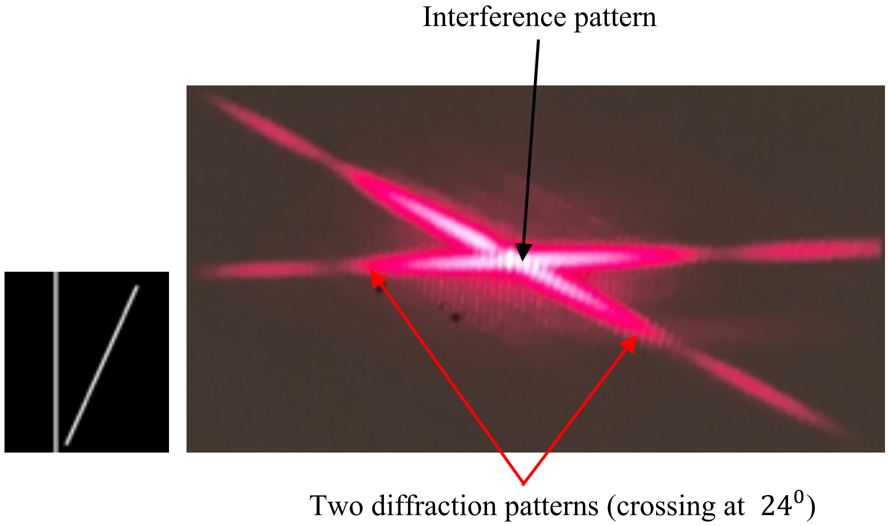


Figure 4.15. Non-parallel two-slit (crossing at 24^0) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-4.11: 27^0 between two slits:
In this experiment, the angle between two slits is 27^0.

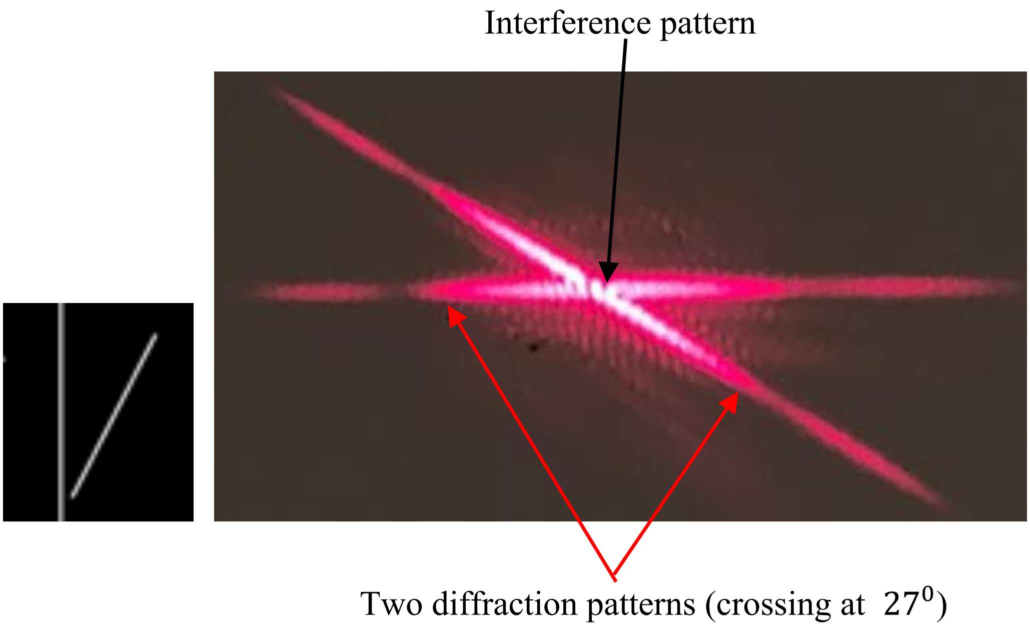


Figure 4.16. Non-parallel two-slit (crossing at 27^0) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-3.12: 30^0 between two slits:
In this experiment, the angle between two slits is 30^0.

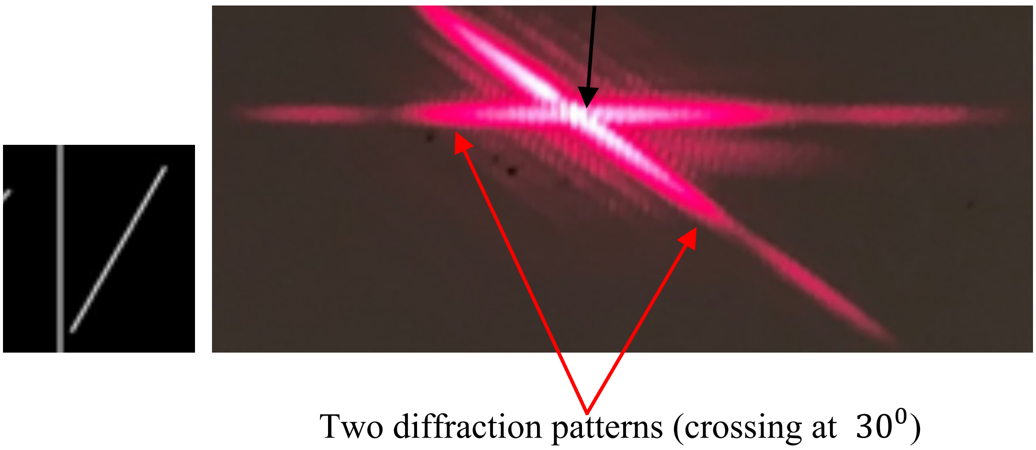


Figure 4.17. Non-parallel two-slit (crossing at 30^0) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-4.13: 33^0 between two slits:
In this experiment, the angle between two slits is 33^0.

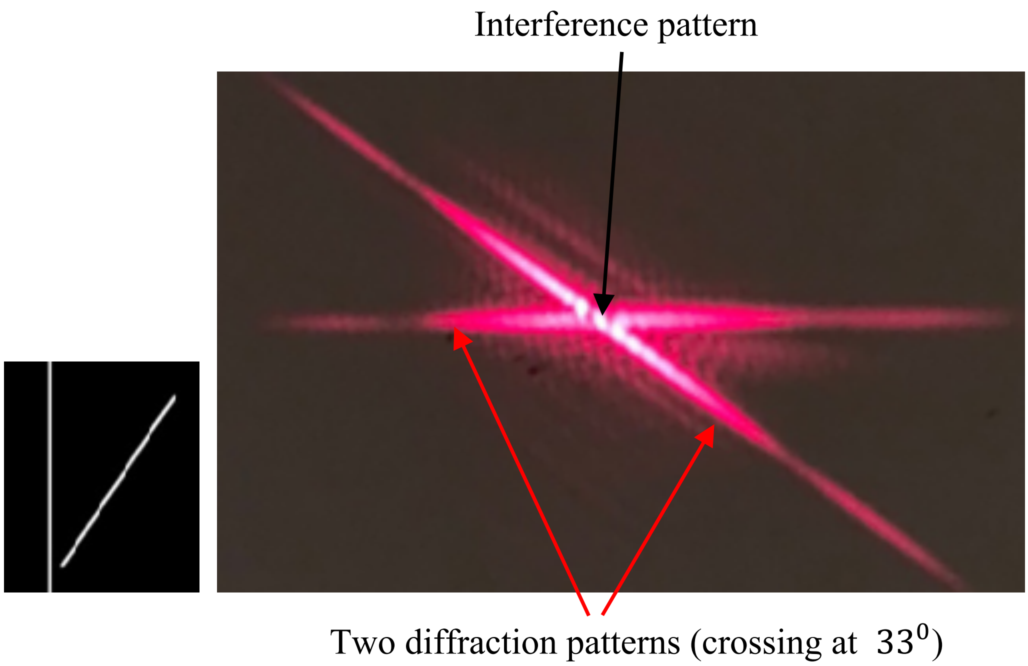


Figure 4.18. Non-parallel two-slit (crossing at 330) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-4.14: 36^0 between two slits:
In this experiment, the angle between two slits is 36^0.

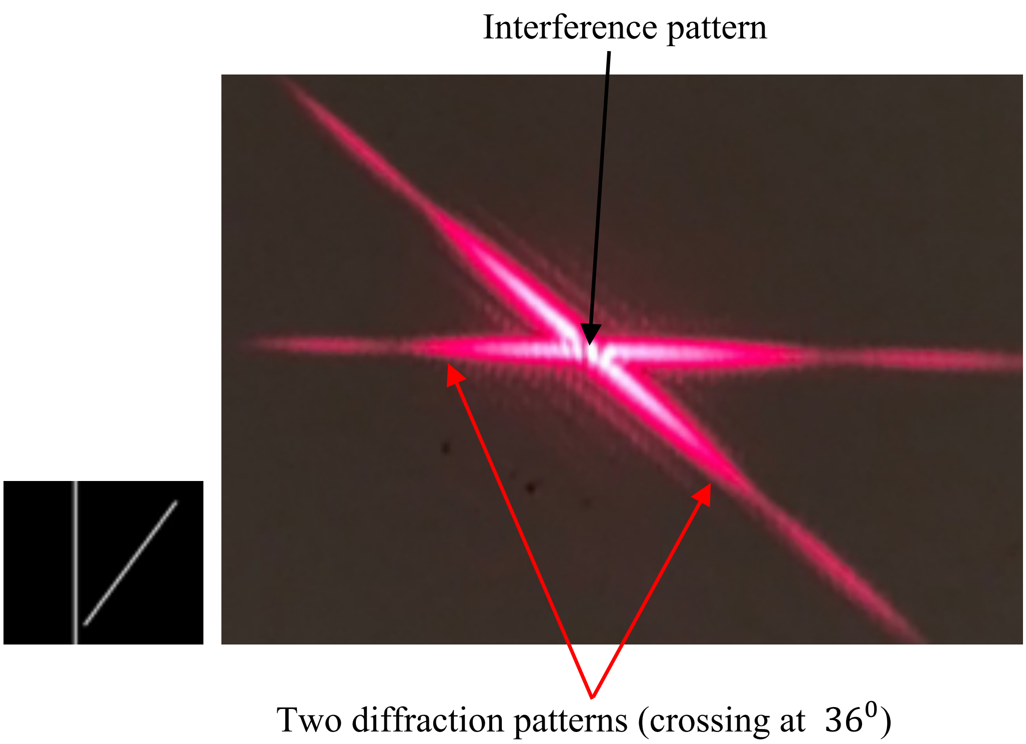


Figure 4.19. Non-parallel two-slit (crossing at 36^0) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-4.15: 39^0 between two slits:
In this experiment, the angle between two slits is 39^0.

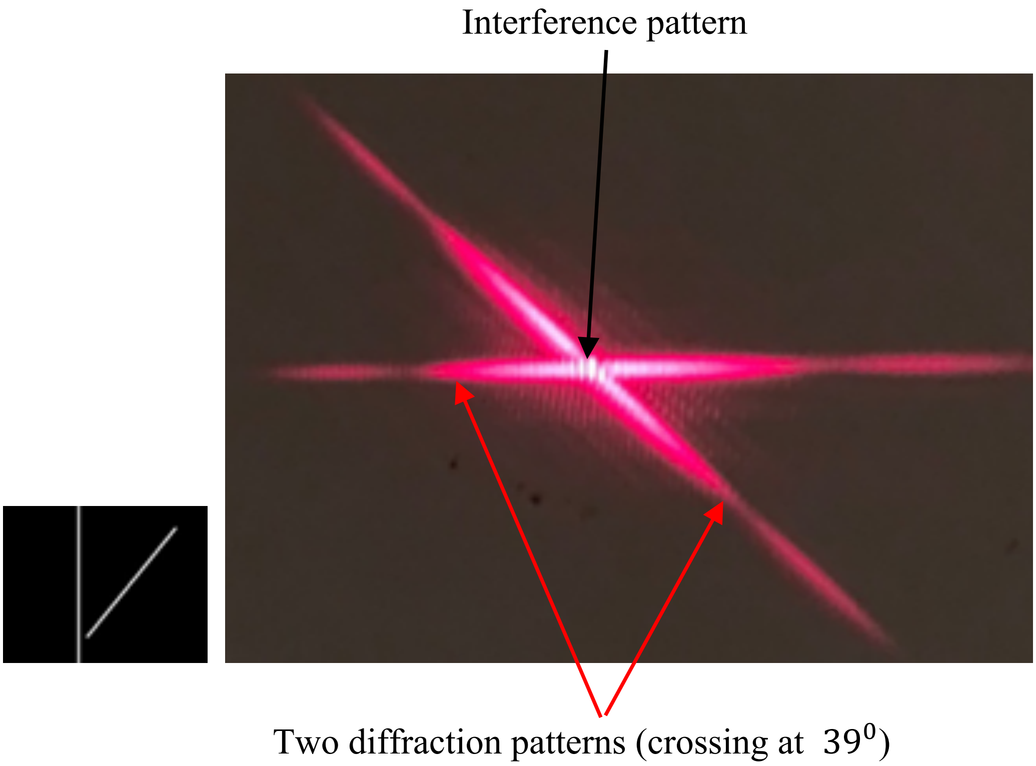


Figure 4.20. Non-parallel two-slit (crossing at 39^0) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-4.16: 42^0 between two slits:
In this experiment, the angle between two slits is 42^0.

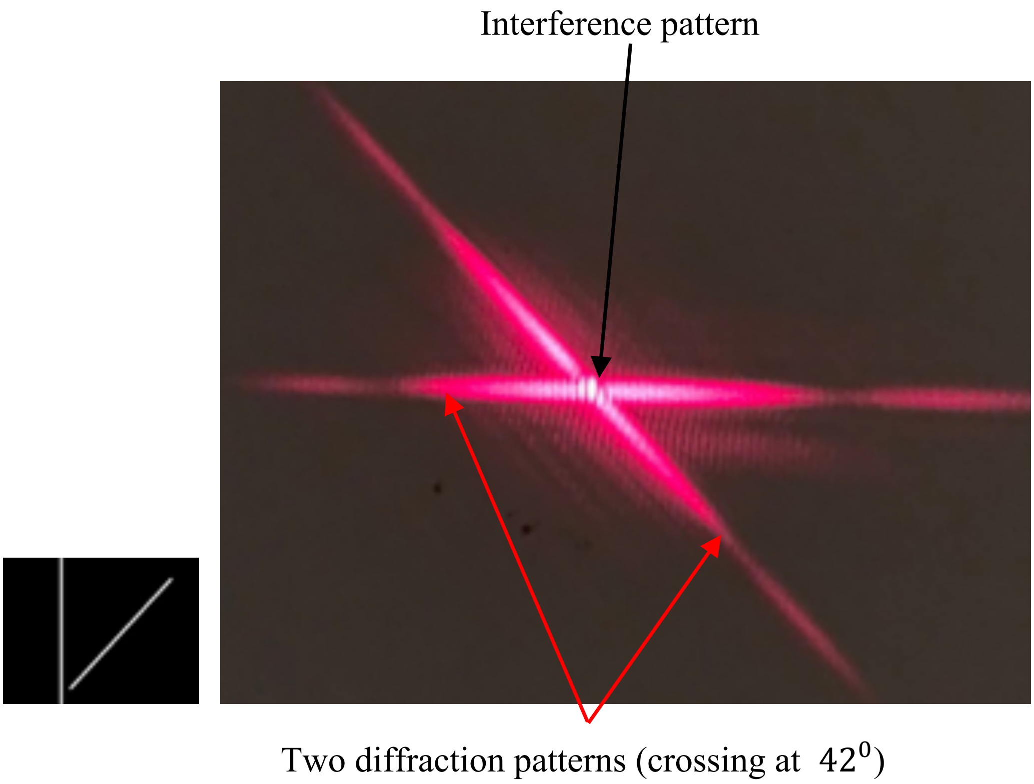


Figure 4.21. Non-parallel two-slit (crossing at 42^0) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-4.17: 45⁰ between two slits:
In this experiment, the angle between two slits is 45^0.

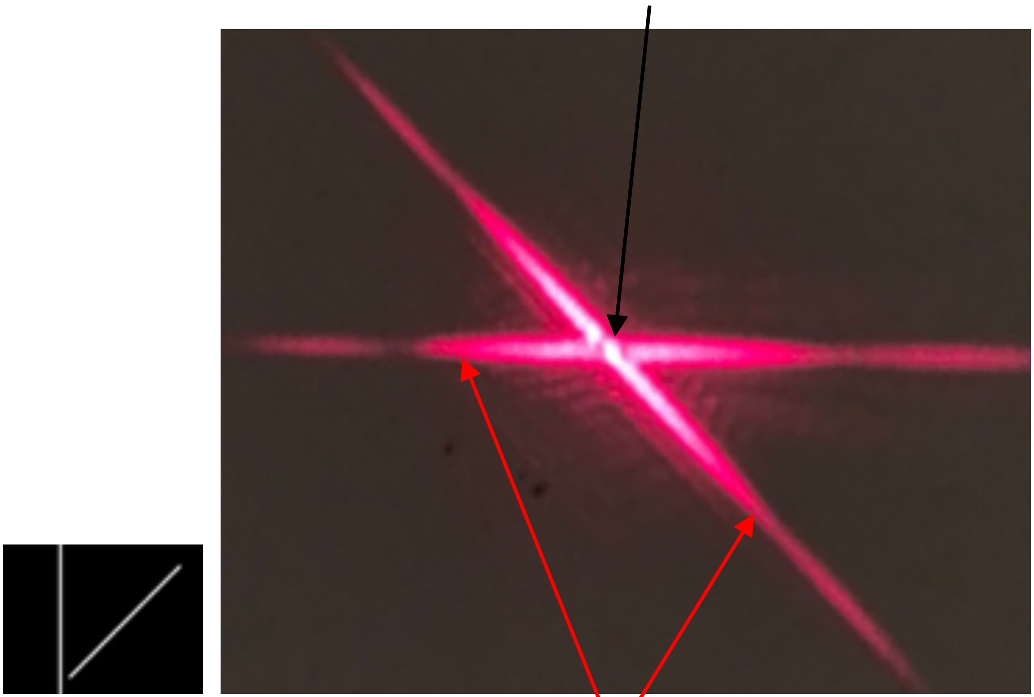


Figure 4.22. Non-parallel two-slit (crossing at 45^0) experiment and hybrid pattern

Observation: there are two diffraction patterns and no partial interference pattern and thus, the pattern is not the hybrid pattern. for the angle larger than 45^0, the pattern is two diffraction patterns crossing, there is no embedded interference pattern.

4.4. Summary

We show that when the angle between two slits is 0^0, the pattern is the interference pattern; increase the angle between the two slits, the patterns are the hybrid pattern; at 45^0, the pattern becomes the diffraction pattern.

The non-parallel two single slits produce the pattern that contains two diffraction patterns and the partial interference pattern embedded in the diffraction patterns, referred as the Interference + diffraction hybrid patterns or the hybrid patterns. The hybrid patterns depend on the angle between two slits.

It is challenge for the wave theories to interpret the hybrid pattern and thus, we suggest that the hybrid pattern indicates the interaction between photons, in addition to the interaction between photons and matters.

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