

Interference Pattern to Hybrid Pattern to Diffraction Pattern — Interaction Between Photons in Non-Parallel Two Slit Experiment

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Abstract

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In this article, we show that 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. Namely, when the angle between two slits varies from 00 to 450, the pattern varies from the interference pattern to the hybrid patterns (i.e., the partial interference pattern embedded in diffraction patterns) to the diffraction patterns. Challenge is to interpret consistently the hybrid patterns.

Interference Pattern to Hybrid Pattern to Diffraction Pattern

--- Interaction Between Photons in Non-Parallel Two Slit Experiment

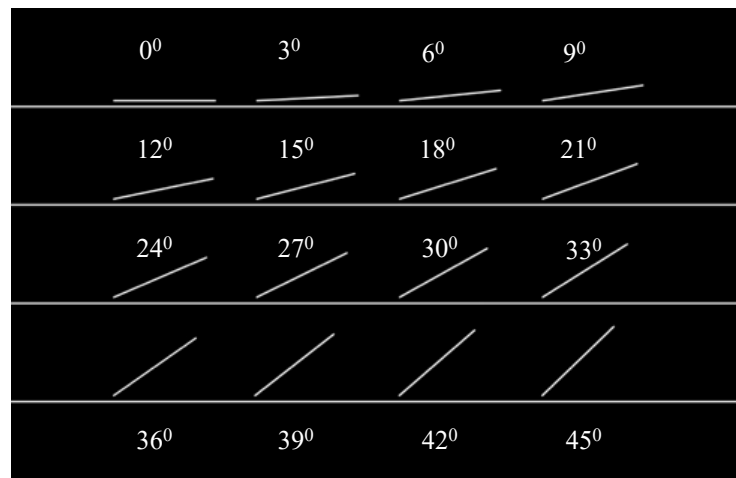
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Abstract

The interference and the diffraction are two basic phenomena in physical optics. We have shown the phenomenon that, in the experiment of two slits with the certain angle between two slits, the partial interference pattern is embedded in the two diffraction patterns, namely, there is the partial interference + diffraction hybrid patterns.



angle	2 slits	Patterns		angle	2 slits	Patterns
0°				3°		
6°				12°		
18°				24°		
42°				45°		

In this article, we show that 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. Namely, when the angle between two slits varies from 0° to 45° , the pattern varies from the interference pattern to the hybrid patterns (i.e., the partial interference pattern embedded in diffraction patterns) to the diffraction patterns. Challenge is to interpret consistently the hybrid patterns.

Keywords: interference pattern, diffraction pattern, hybrid pattern, pattern evolution, double slit, non-parallel two slits, angle-dependence of patterns.

1. Introduction

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. By definition, the two slits are perpendicular to the cross-section of the double slit.

Recently, it has been shown [1] 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 (Appendix).

In this article we show the phenomena: when the angle between two slits increases from the 0° to 45° , the interference pattern becomes the partial interference + diffraction hybrid patterns and, finally, become the diffraction patterns, the pattern-evolution phenomena. In the two 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.

We suggest that the hybrid patterns indicate the interaction between photons.

Challenge is to interpret consistently the hybrid patterns and its evolution.

2. Standard Interpretations of double slit and single slit experiments

Let us review the standard interpretations of the double slit and the single slit experiments first. Then we experimentally show that the standard interpretations cannot interpret the hybrid pattern, and how the interference pattern evolve to the hybrid pattern and then to the diffraction pattern, when the angle between two slits increases.

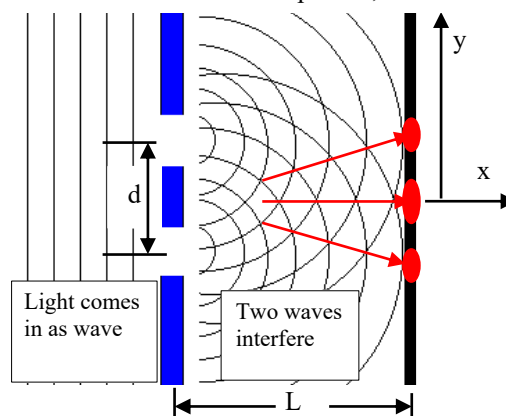


Figure 1 Standard Interpretations of double slit experiment

Three standard interpretations of the double slit experiments are:

- (1) **The classical optical wave** description of the double slit experiments:

$$y = m \frac{\lambda L}{d}. \quad (1)$$

Where $L \gg d \gg \lambda$. Where “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

$$\Delta y \propto 1/d. \quad (2)$$

(2) **The EM wave** description of the double slit experiments:

Assume the waves are coherent plane waves, the intensity I is:

$$I = E_1^2 + E_2^2 + 2\mathbf{E}_1 \cdot \mathbf{E}_2. \quad (3)$$

Where \mathbf{E}_1 and \mathbf{E}_2 are the electric fields at the slit-1 and the slit-2 respectively.

(3) **The probability wave** description of the double slit experiments:

$$P_y = |\psi_1(r)|^2 + |\psi_2(r)|^2 + 2\text{Re}[\psi_1^*(r)\psi_2(r)]. \quad (4)$$

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:

(1) **The classical optical wave** description of the destructive diffraction of the single slit experiments is:

$$y = m \frac{\lambda L}{a}. \quad (5)$$

Where “a” is the width of the single slit.

(2) **The EM wave** description of the single slit experiments:

Assume the waves are coherent plane waves, the intensity I is proportional to the time average of E^2 :

$$I = \langle E^2 \rangle. \quad (6)$$

Where E^2 is the electric fields at the slit.

Note: as shown in Figure 1, the two slits are perpendicular to the x-y plane, i.e., the cross-section of the double slit. Equation (1), (3) and (4) show that the thickness of the cross-section is irrelevant, and the angle between two slits is irrelevant, two slits are parallel.

3. Experiments: setups

3.1. Diaphragm

In this article, we study the non-parallel two slits. For this purpose, we utilize the diaphragm containing 16 two-slits with different angles: $0^\circ - 45^\circ$ (Figure 2).

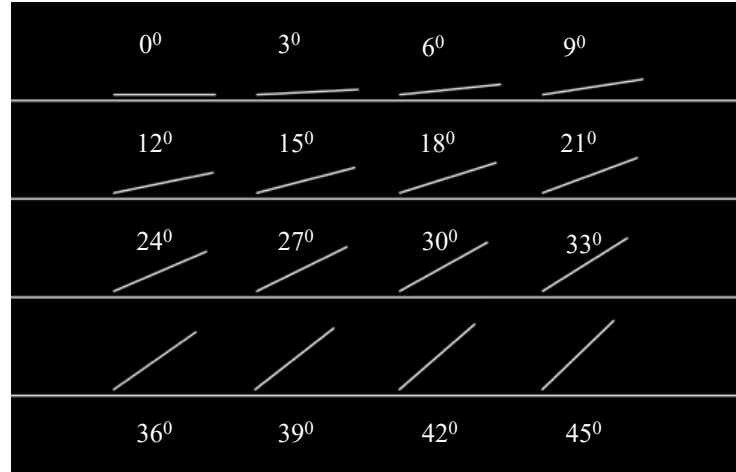


Figure 2. Diaphragm of parallel two-slits and non-parallel two-slits with angles: $0^\circ - 45^\circ$

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

3.2. Experiment setup

The same experiment setup (Figure 3 and Figure 4) is for Experiment-1 to Experiment-16, but with different apparatuses of two-slits. We set the distance between the diaphragm and the screen 1400 mm.



Figure 3. Experiment setup

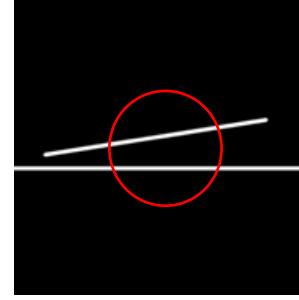


Figure 4. Spot of laser at non-parallel two-slits

The laser with beam-diameter 3 mm aims at the non-parallel two-slits, as shown by the red circle in Figure 4.

4. Angle-dependence of patterns of non-parallel two-slits experiments

Experiment-1: 0° between two slits:

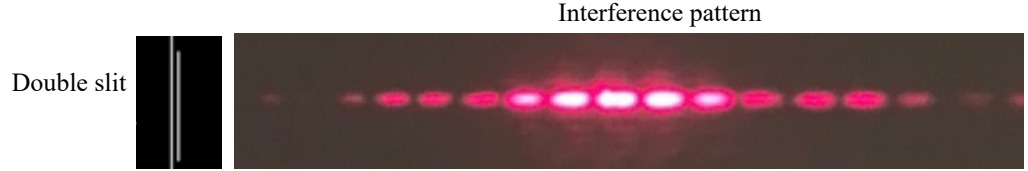


Figure 5. Standard double slit experiment and interference pattern

Observation: the parallel-two-slit (the normal double slit) produces the interference pattern, which can be interpreted by all three standard wave theories, Equation (1) to (4). Figure 5 clearly shows the fringes $m = \pm 6$.

Experiment-2: 3° between two slits:

In this experiment, the angle between two slits is 3° .

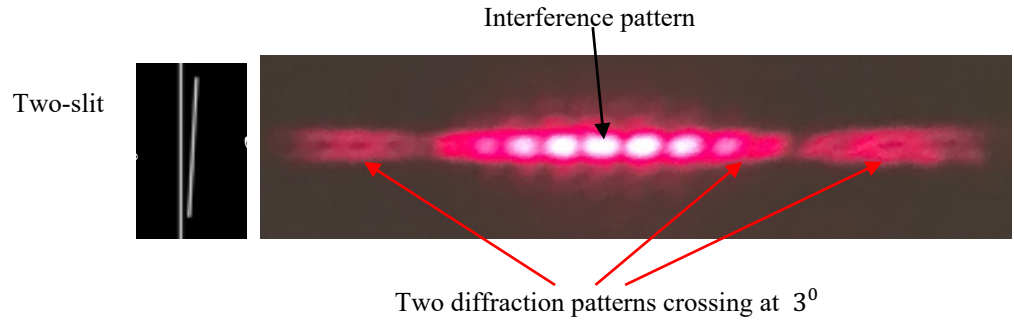


Figure 6. Non-parallel two-slit (crossing at 3°) experiment and hybrid pattern

Observation: we observe the hybrid pattern, i.e., the partial interference pattern embedded in the diffraction pattern. Two diffraction patterns are not 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, Eq. (1) to (6).

Experiment-3: 6° between two-slits:

In this experiment, the angle between two slits is 6° .

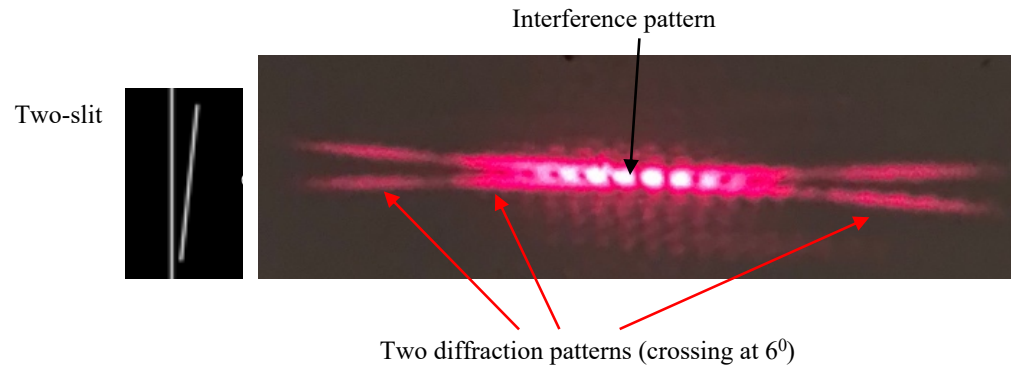


Figure 7. Non-parallel two-slit (crossing at 6°) experiment and hybrid pattern

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

Experiment-4: 9° between two slits:

In this experiment, the angle between two slits is 9° .

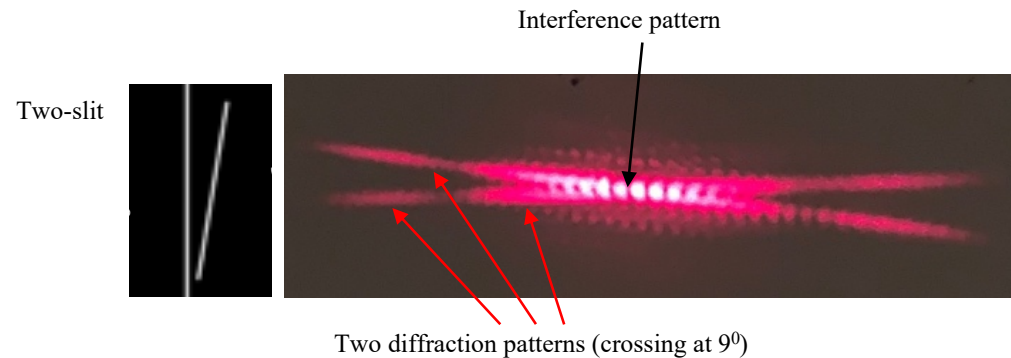


Figure 8. Non-parallel two-slit (crossing at 9°) experiment and hybrid pattern

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

Experiment-5: 12° between two slits:

In this experiment, the angle between two slits is 12° .

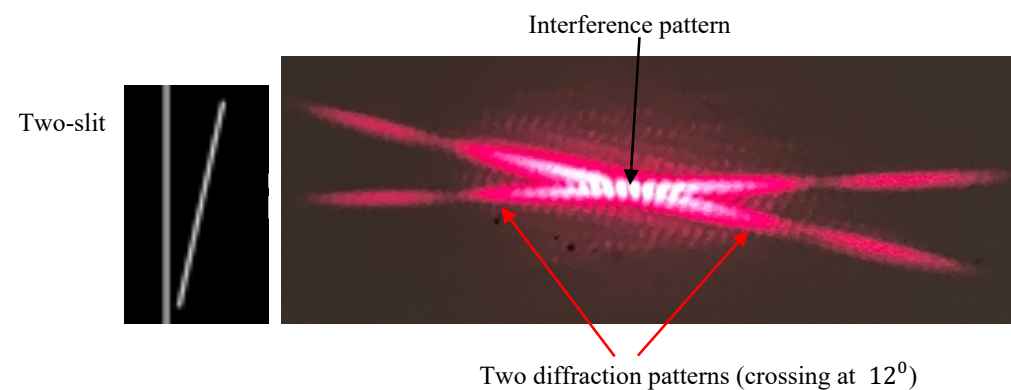


Figure 9. Non-parallel two-slit (crossing at 12°) experiment and hybrid pattern

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

Experiment-6: 15° between two slits:

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

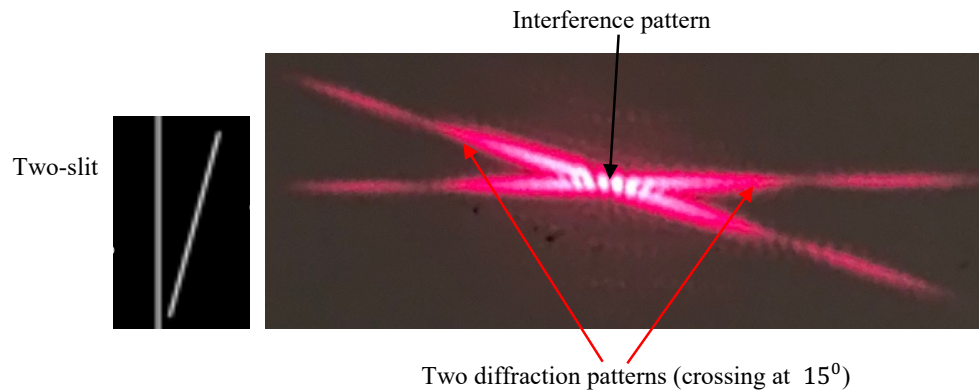


Figure 10. Non-parallel two-slit (crossing at 15°) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-7: 18° between two slits:

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

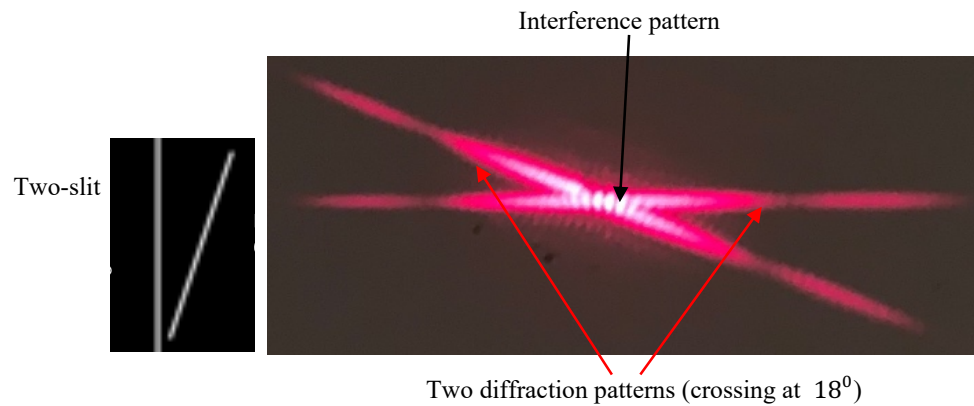


Figure 11. Non-parallel two-slit (crossing at 18°) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-8: 21° between two slits:

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

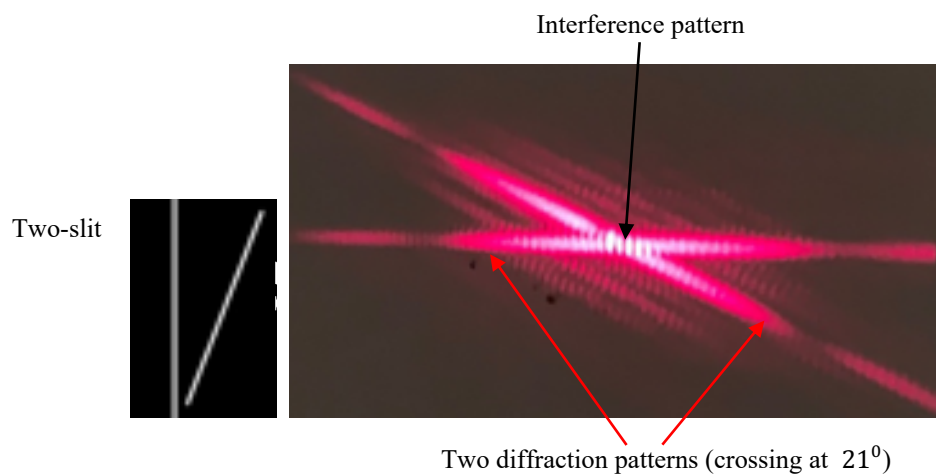


Figure 12. Non-parallel two-slit (crossing at 21°) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-9: 24° between two slits:

In this experiment, the angle between two slits is 24° .

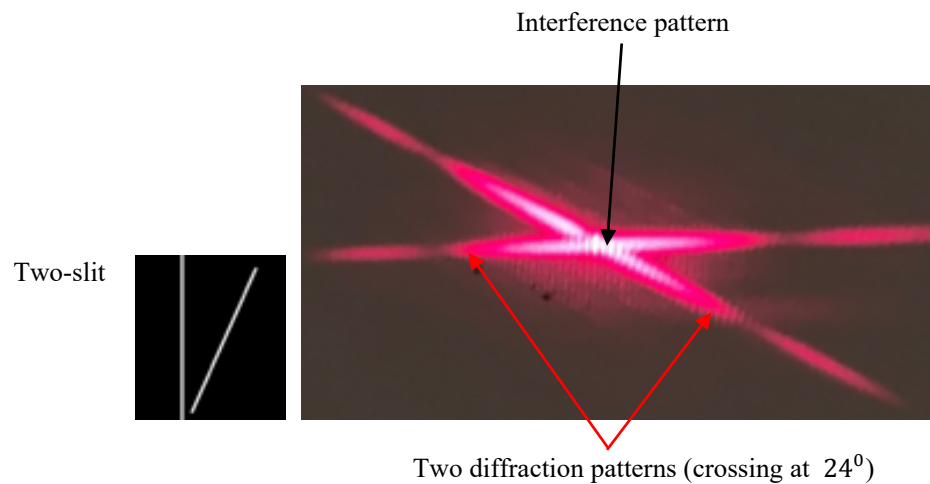


Figure 13. Non-parallel two-slit (crossing at 24°) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-10: 27° between two slits:

In this experiment, the angle between two slits is 27° .

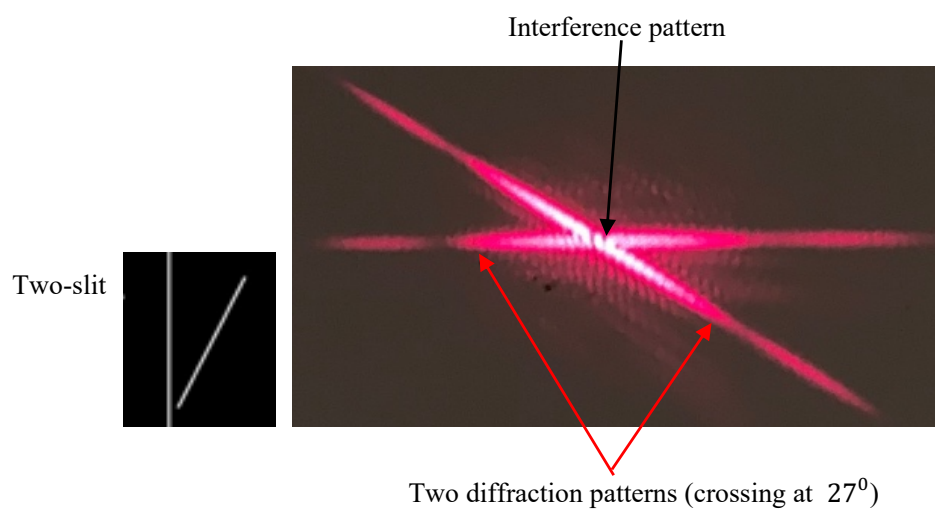


Figure 14. Non-parallel two-slit (crossing at 27°) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-11: 30° between two slits:

In this experiment, the angle between two slits is 30° .

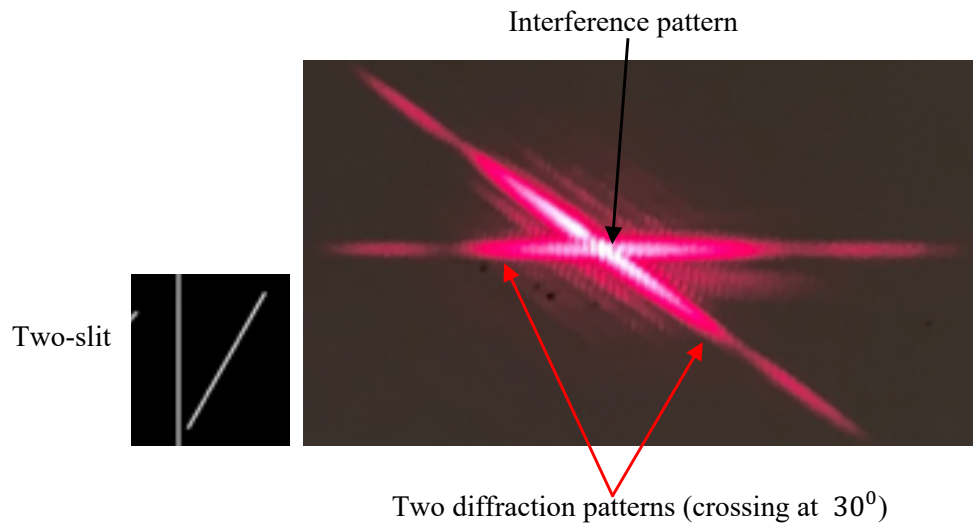


Figure 15. Non-parallel two-slit (crossing at 30°) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-12: 33° between two slits:

In this experiment, the angle between two slits is 33° .

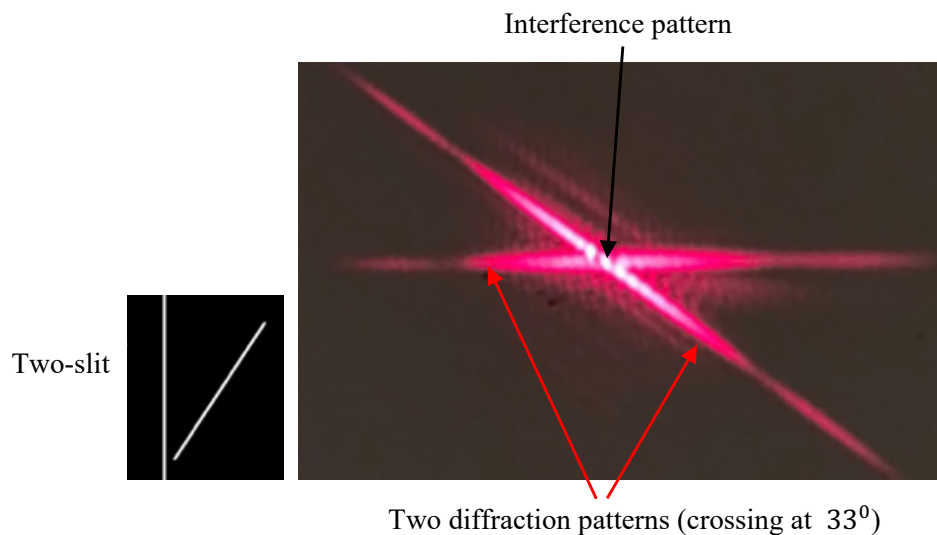


Figure 16. Non-parallel two-slit (crossing at 33°) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-13: 36° between two slits:

In this experiment, the angle between two slits is 36° .

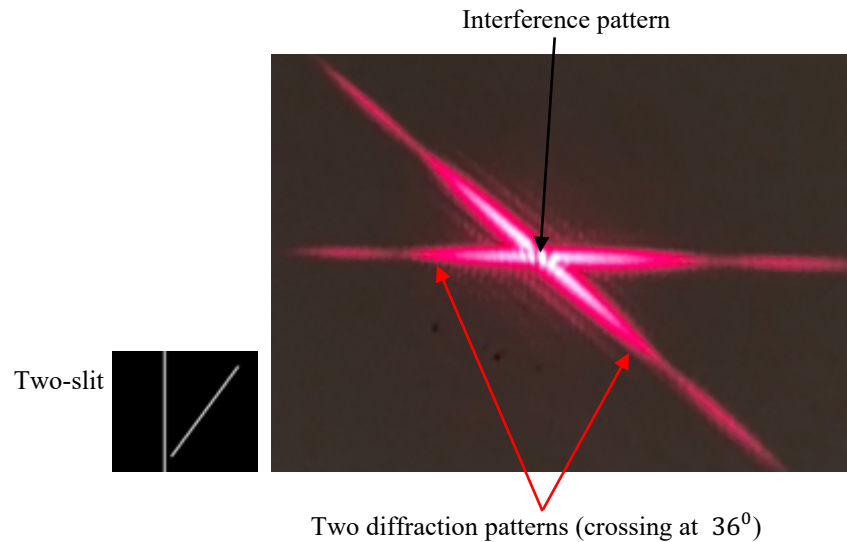


Figure 17. Non-parallel two-slit (crossing at 36°) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-14: 39° between two slits:

In this experiment, the angle between two slits is 39° .

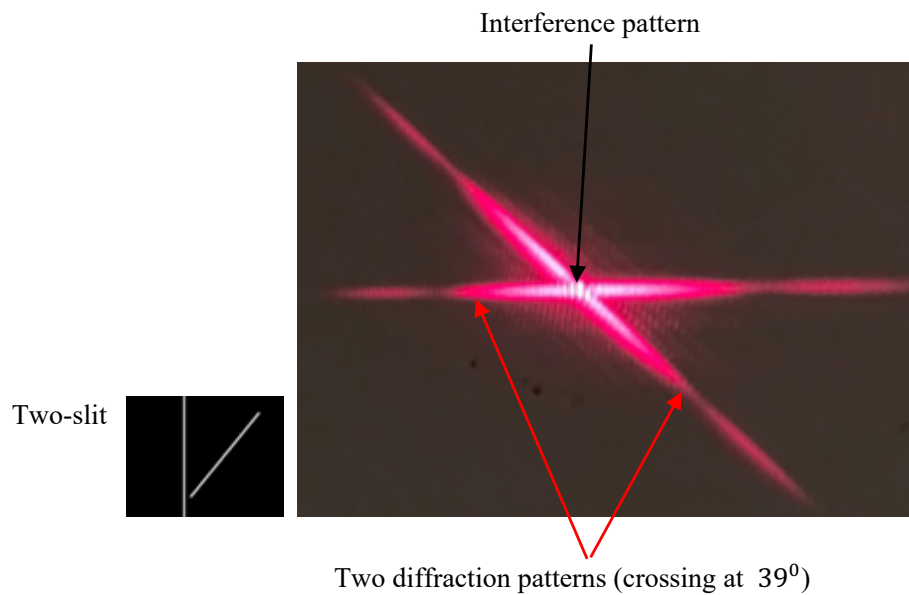


Figure 18. Non-parallel two-slit (crossing at 39°) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-15: 42° between two slits:

In this experiment, the angle between two slits is 42° .

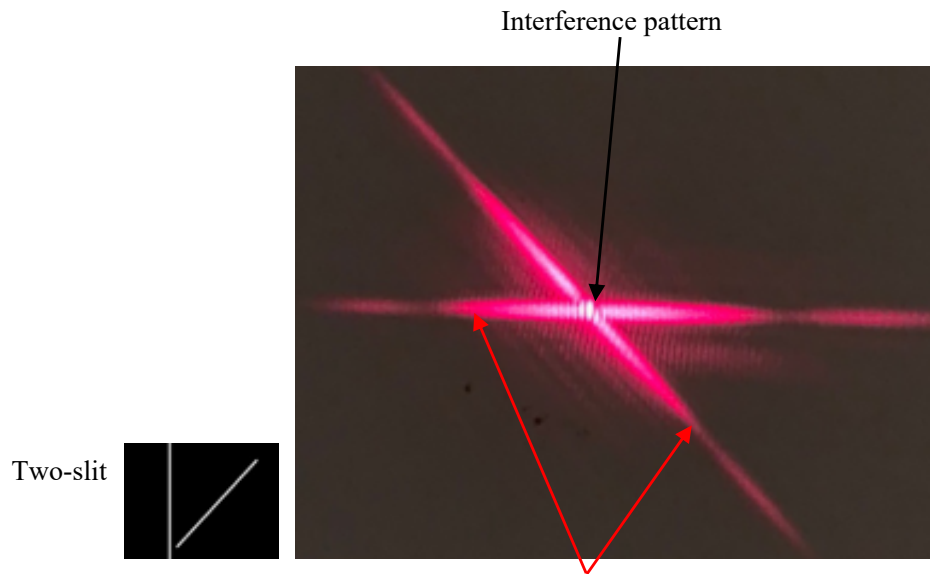


Figure 19. Non-parallel two-slit (crossing at 42°) experiment and hybrid pattern

Observation: we observe the hybrid pattern.

Experiment-16: 45° between two slits:

In this experiment, the angle between two slits is 45° .

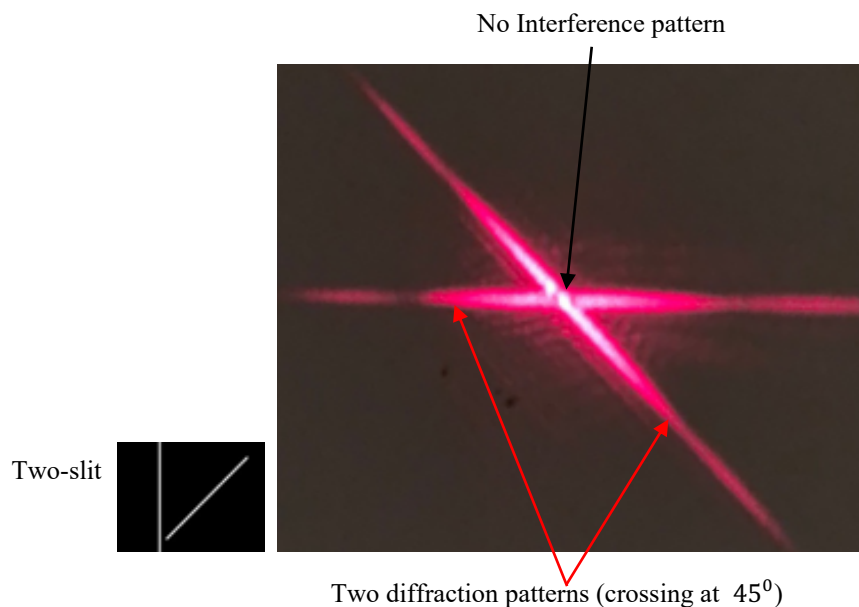


Figure 20. Non-parallel two-slit (crossing at 45°) experiment and hybrid pattern

Observation: there are two diffraction patterns and no partial interference pattern and thus, not the hybrid pattern.

5. Summary

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

angle	2 slits	Patterns		angle	2 slits	Patterns
0°				3°		
6°				9°		
12°				15°		
18°				21°		
24°				27°		
30°				33°		
36°				39°		
42°				45°		

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.

Appendix

Experiment-A: The angle between two slits is 17.5° . The experiment contains two steps.

First step: utilizing the experiment setup in Figure 3. The novel pattern shows in Figure A1.

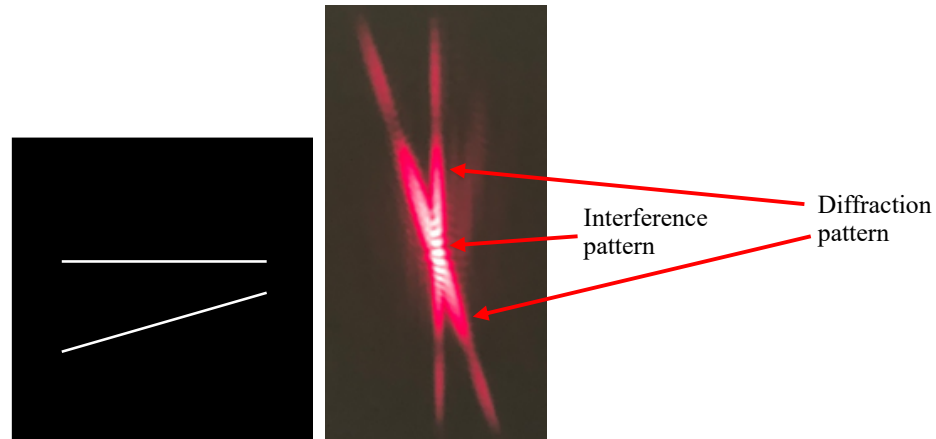
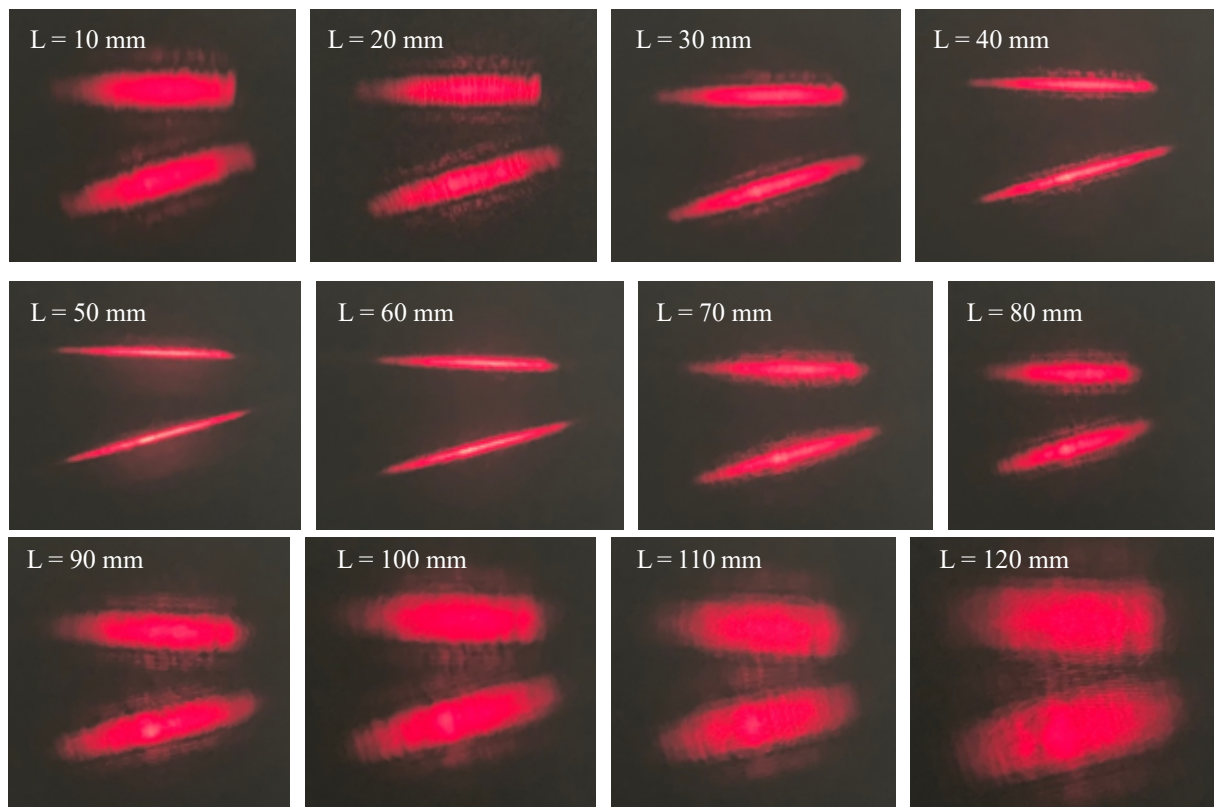


Figure A1. Novel pattern: interference pattern embedded in two diffraction patterns

Observation: The interference pattern is embedded in the two diffraction patterns; we referred the pattern as the Interference pattern + diffraction hybrid pattern. 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.

Second step: to study how this pattern is produced, let us study the pattern evolution by utilizing the experiment setup in Figure 3 and adding the lens between the diaphragm and the screen, i.e., the distance-dependence of the patterns.



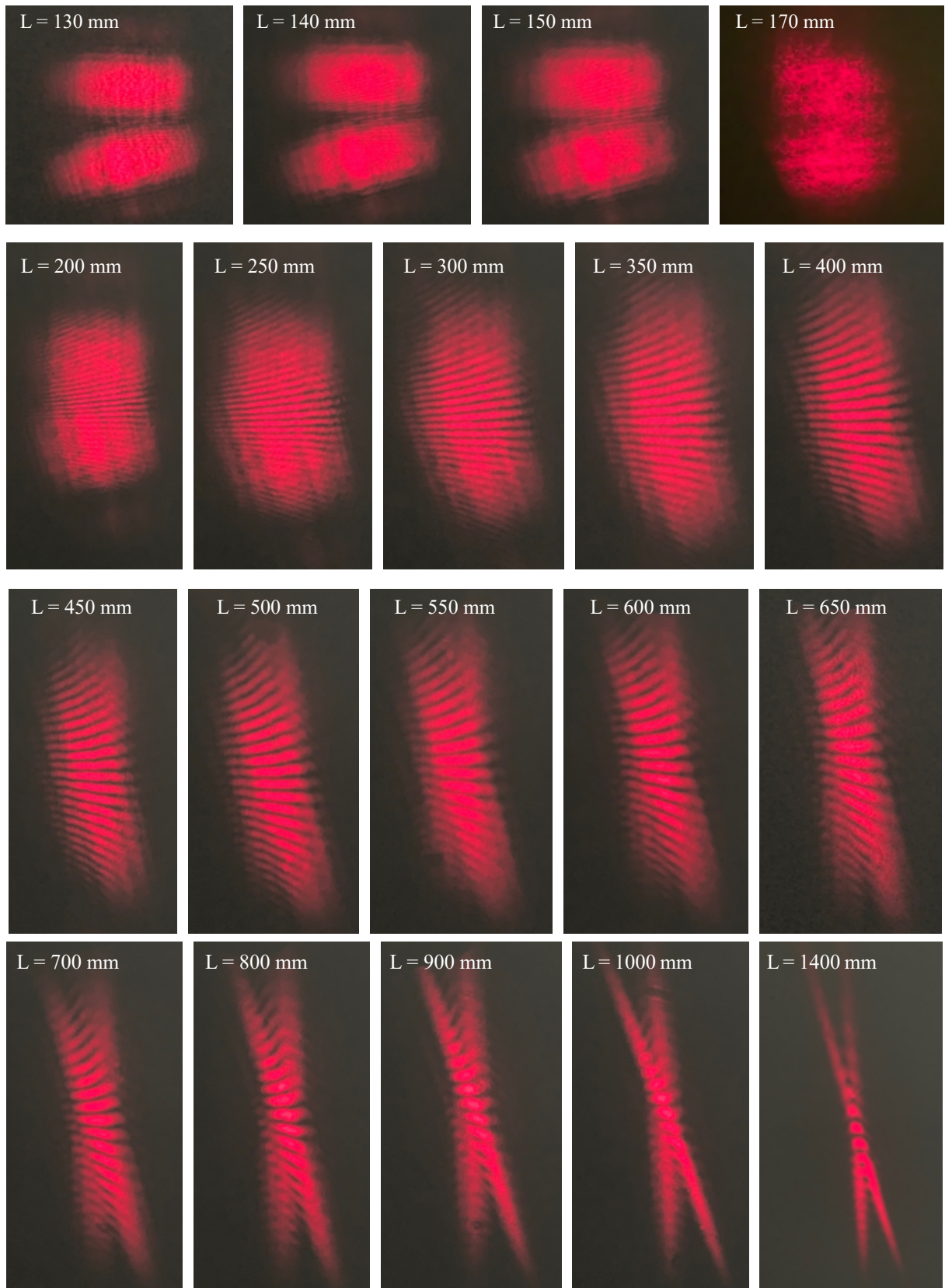


Figure A2. Pattern evolution: from Particle Patterns to Interference + Diffraction Hybrid Patterns

Observation: Figure A2 shows the pattern evolution. The patterns are the Particle patterns, when the lens is placed at $L = 10 - 100$ mm. For the lens at $L = 150 - 1000$ mm, we call the patterns the Transition patterns. When the lens at $L \geq 1400$ mm, the patterns are the Interference + Diffraction Hybrid Patterns.

Reference

- [1] Hui Peng, "Interference + Diffraction Hybrid Patterns of Novel Double Slit Experiment --- Interference Pattern Embedding in Diffraction Pattern. TechRxiv. Preprint. <https://doi.org/10.36227/techrxiv.24329569.v1> Oct. 2023.