Novel Double Slit and Cross-Double Slit Experiments—Interference Patterns Depending on Orientation of Diaphragm

Hui Peng (✉ davidpeng1749@gmail.com)

Research Article

Keywords: double slit experiments, cross-double slit experiments, interference pattern, wave interpretation

DOI: https://doi.org/10.21203/rs.3.rs-653201/v1

License: © This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License
Novel Double Slit and Cross-Double Slit Experiments
--- Interference Patterns Depending on Orientation of Diaphragm

Hui Peng
Email: davidpeng1749@gmail.com

Abstract Young’s double slit experiments represent the mystery of quantum mechanics. To explore the mystery, in this article, we report experimental results that show novel phenomena that the interference patterns of the double slit and cross-double slit experiments depend on the orientation of the diaphragms. Those experiments provide comprehensive data for developing/testing a theoretical model.

Keywords: double slit experiments, cross-double slit experiments, interference pattern, wave interpretation

1. Introduction

Young’s double slit experiment was performed in 1801 [1] [2], which, 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].

Recently, to study the mystery of double slit experiments and test the wave interpretation and trajectory interpretation, cross-double slit experiments [5] [6] and comprehensive double slit experiments [7] [8] [9] have been proposed/performed. In this article, we show novel phenomena of the double slit and cross-double slit experiments.

2. Apparatuses

The experiments utilize a laser source, the diaphragm of the standard double slit (Figure 1a), the diaphragm of the cross-double slit (Figure 1b), and a protractor (Figure 1c).

![Figure 1 Apparatus](a) (b) (c)
3. Novel Phenomena: Interference Patterns Depending on Orientations of Double Slit

The standard optical equation describing the interference pattern of the double slit experiments relates the positions of fringes, wave length, the spacing between two slits and distance from the double slit to detector/screen as $y_{\text{const}} = \frac{m \lambda L}{d}$. This equation is derived for a special situation that the source is on the normal vector of the plane of the double slit.

We are interested in how the interference patterns vary with angle of the diaphragm of double slit/cross-double slit.

Let us start with a schematic drawing (Figure 2). The double-slit-AB is in the y-z plane, slit A and slit B are along the z-axis, its normal vector is along the x-axis and points to source, the coordinates of slit-A and slit-B are $y_A = d/2$ and $y_B = -d/2$, the spacing between slits A and B is “d”, and photons travel along the negative x direction.

![Figure 2 Standard diaphragm of double slit and its pattern](image)

We study the orientation-dependence of the interference pattern of a standard double-slit rotating around the x-axis, y-axis, and z-axis, respectively.

3.1. Rotating Double Slit Around X-axis: Normal Vector.

We consider two situations: discrete and continuous rotations.

**First situation**: discrete rotation.

**Experiment-1**: (Figure 3). Rotating the double-slit clockwise a discrete angle, 15 degree.

![Figure 3 Double-slit rotates around x-axis at angle and its pattern](image)

**Observation**: the pattern rotates the same angle clockwise and without change.

The interference pattern is perpendicular to the double slit.
**Second situation**: continuous rotation

The combination of the interference patterns of the cross-double slit experiments with different number of double slits crossing to each other suggests that the double slit and cross-double slit have rotation-invariance around their normal vectors. If we increase the number of double slits that intersect at the same spot, the shape of the intersection will approach a circular disc, each slit is tangent to the intersection and forms disc-3, which is surrounded by ring-2 (Figure 4a). The zero-order fringe rotates at the same spot, and forms a bright fringe 0, while the rotation of its first-, second- and third-order fringes form bright rings 1, the dark fringes form dark rings 2, and so on (Figure 4b).

![Figure 4 Predicted pattern of continuously rotating double slit/cross-double slit around x-axis](image)

The above prediction has been tested by the experiment.

**Experiment-2**: The apparatus consisting of obstacle 1 with a hole, disc 3 placed at the center of hole-2 and leaving ring-shape gap 2 between disc 3 and obstacle 1 (Figure 5).

![Figure 5 Rotation symmetry of double slit/cross-double slit](image)

**Observation**: Figure 5 indicates that double slit and cross-double slit have rotation-invariance around their normal vector.

**3.2. Rotate Double Slit Around Y-axis**

The interference pattern before rotating is shown below (Figure 6), for the purpose of comparison,
Experiment-3: The double slit rotates 75 degree around Y-axis (Figure 7, not to scale).

**Observation:** the interference pattern has no noticeable change, except dimmer.

3.3. Rotating Double Slit Around Z-axis

The experiments show the orientation-dependence of the interference patterns visually.

Experiment-4: The diaphragm at the original orientation and its interference pattern (Figure 8).

Experiment-5 (Figure 9): The diaphragm rotates 30° from the original orientation.

Experiment-6 (Figure 10): The diaphragm rotates 45° from the original orientation.
**Experiment-7** (Figure 11): The diaphragm rotates $60^\circ$ from the original orientation.

![Figure 11 The diaphragm rotates 60°](image)

**Experiment-8** (Figure 12): The diaphragm rotates $75^\circ$ from the original orientation.

![Figure 12 The diaphragm rotates 75 degree](image)

Figure 9 to figure 12 show the evolution of the interference pattern varying with angles of the double slit rotating around the z-axis.

The formula describing the interference pattern of double slit at an angle relative to the z-axis has been derived:

$$y_1 + y_2 = \frac{m\lambda}{d}L_2\sqrt{1 + (\tan\theta)^2}$$

The detail derivation is shown in Appendixes A-2.

**4. Novel Phenomena: Interference Patterns Depending on Orientations of Cross-Double Slit**

**4.1. Rotating Cross-Double Slits Around Z-axis: Two Double Slits Crossing**

We study the orientation-dependence of the pattern of a cross-double slit rotating around the X, Y and Z-axis. A cross-double-slit apparatus consists of source, cross-double-slit and screen. Let us consider a simple cross-double slit that consists of double-slit-AB and double-slit-CD, and double-slit-AB is perpendicular to double-slit-CD (Figure 13).
We have shown that each double slit of the cross-double slit creates the interference pattern independently [7]. The pattern of the cross-double slit-ABCD is the combination of the two patterns created by the double slit-AB and double slit-CD.

When the cross-double slit-ABCD rotates an angle around X-axis (Figure 14), the pattern is the combination of the patterns created respectively by the double slit-AB and the double slit-CD rotating the same angle.

The patterns created by rotating around Y-axis and around Z-axis are the same, since the double slit-AB is identical the double slit-CD, but rotating 90 degree. So we only consider the situation of rotating around Z-axis.

**Experiment-9** (Figure 16): The cross-double slit at the original orientation.

**Experiment-10** (Figure 17): The diaphragm rotates $30^\circ$ around Z-axis.
**Experiment-11** (Figure 18): The diaphragm rotates 45° around Z-axis.

![Figure 18 Diaphragm rotates 45°](image1)

**Experiment-12** (Figure 19): The diaphragm rotates 60° around Z-axis.

**Experiment-13** (Figure 20): The diaphragm rotates 75° around Z-axis.

![Figure 20 Diaphragm rotates 75°](image2)

**Conclusion**: The interference patterns of double slit-AB have the same orientation-dependence as experiment-5 to experiment-8. While the interference patterns created by double slit-CD at different rotation-angles have no noticeable change.

### 4.2. Rotating Cross-Double Slits Around Z-axis: Six Double Slits Crossing

Now consider a cross-double slit that consists of six double slits crossing to each other (Figure 21). The Z-axis is between two vertical double slits and parallel to them. The laser source is on the normal vector of the cross-double slit at the original orientation. Here we consider the rotation of the cross-double slit around the Z-axis.

![Figure 21 Cross-double slit and its pattern: Rotating 0°](image3)
**Experiment-14** (Figure 22): The cross-double slit rotates 60° around Z-axis.

![Figure 22 Rotating 60°](image1) ![Figure 21 Rotating 0°](image2)

For comparison, we put Figure 21 and Figure 22 side by side, which clearly show the difference.

**Experiment-15** (Figure 23): The cross-double slit rotates 75° around the Z-axis.

![Figure 23 Rotating 75°](image3) ![Figure 22 Rotating 60°](image4)

**Observation:** when the rotating angle becomes larger: (1) the distances between two fringes of patterns created by non-horizontal double slits become larger; (2) the patterns created by the tilt-double slits tilt towards the horizontal interference pattern; (3) the distance between fringes created by the vertical double slit is largest; (4) the vertical patterns created by the horizontal double slit have no noticeable change.

**Conclusion:** The interference patterns created by the tilt double slits tend to closer to Y-axis.

### 4.3. Rotating Cross-Double Slits Around Z-axis: Three Double Slits Crossing

Now to show the orientation-dependence of the interference pattern of the tilt-double slit, especially the novel phenomena that the patterns created by the tilt-double slits tilt towards the horizontal pattern, let us consider two double slits crossing at 15° and 30° to the vertical slit respectively (Figure 24 and Figure 27). The laser source is on the normal vector of the diaphragm for the original position, rotating 0°. When the diaphragm rotates, the laser source stay.

**Experiment-16** (Figure 24): three double slits cross to each other at 15° and 30°. The diaphragm is at the zero-degree position.
Observation: the interference patterns perpendicular to the double slits created them, respectively. The angles between the slits are the same as that between the interference patterns.

Experiment-17 (Figure 25): the diaphragm rotates 60° around Z-axis.

Observation (Figure 25): the angles between two interference patterns are smaller than that shown in Figure 24. The distances between two fringes of the same pattern are larger than that in Figure 24.

Experiment-18 (Figure 26): the diaphragm rotates 75° around Z-axis

Observation (Figure 26): the angles between two interference patterns are smaller than that shown in Figure 25. The distances between two fringes are larger than that shown in Figure 25.

Conclusion: The interference patterns created by two tilt double slits tend to closer to the Y-axis

4.4. Rotating Cross-Double Slits Around Y-axis: Three Double Slits Crossing

Experiment-19 (Figure 27): the diaphragm rotates 0° around Y-axis
Let us rotate the diaphragm around Y-axis.

**Experiment-20** (Figure 28): the diaphragm rotates 45° around Y-axis.

Experiment-21 (Figure 29): the diaphragm rotates 60° around Y-axis.

Experiment-22 (Figure 30): the diaphragm rotates 75° around Y-axis.

**Observation:** the angles between two interference patterns created by a tilt double slit and vertical double slit respectively become larger and larger when the rotating angle of the diaphragm becomes larger and larger. The interference patterns of the vertical double slit have no noticeable change.

**Conclusion:** The interference patterns created by two tilt double slits tend to closer to the Z-axis.

5. **Summation**

We show that the interference patterns of the double slit and cross-double slit depend on the orientation of the diaphragms. It is a challenge to interpret the experiments in Section 4 consistently.

The significances of those experiments are to provide comprehensive phenomena/data for developing theoretical model to explore the mystery of the double slit experiments.

**Appendixes**

**(A-1) Novel Multi-Slits for Exploring Mystery of Cross-Double Slit**

To explore the mystery of the double slit/cross-double slit, we designed novel multi-slits in which a cross-double slit is divided into different parts/sections to test the function of each part/section of the cross-double slit. The widths of every slit are the same, and spacing between all of vertical double slits and between all of horizontal double slits are the same.

The normal Cross-double-slit-ABCD, the double slit-AB perpendicular to the double slit-CD, is shown in Figure A1 for the purpose of comparation.

The novel multi-slits are shown below.
Novel Multi-Slits-1: Figure A2 shows the intersection of the cross-double slit-ABCD. The purpose: testing whether the intersection of the cross double slit creates the whole interference pattern.

Novel Multi-Slits-2 (Figure A3): there are gaps between the intersection and the parts of slit-A, -B, -C and -D.

Novel Multi-Slits-3 (Figure A4)

Novel Multi-Slits-4 (Figure A5).

Novel Multi-Slits-5 (Figure A6).

Novel Multi-Slits-6 (Figure A7).

Novel Multi-Slits-7 (Figure A8)

Novel Multi-Slits-8 (Figure A9)

Novel Multi-Slits-9 (Figure A10)

Novel Multi-Slits-10 (Figure A11)

Novel Multi-Slits-11 (Figure A12)
(A-2) Derivation of Orientation-dependence Formular of Interference Pattern of Double Slit

The schematic drawing is the following.

Whether the two waves interfere is determined by the value of \((x_1 + x_2)\). The requirement of the interference of two waves is that the path difference is

\[
x_1 + x_2 \approx m\lambda
\]

Where

\[
x_1 = dsinb
\]
\[
x_2 \approx d sina
\]

\[
sina = \frac{y_2}{L_1} = \frac{y_2}{\sqrt{L_2^2 + y_2^2}} = \frac{y_2}{L_2 \sqrt{1 + \frac{y_2^2}{L_2^2}}}
\]
\begin{align*}
sin b & \approx \tan b \approx \frac{y_1}{L_1} \\
m\lambda = x_1 + x_2 & \approx d(sina + sinb) = \frac{d}{L_1}(y_1 + y_2) \\
y_1 + y_2 &= \frac{m\lambda}{d}L_1 = \frac{m\lambda}{d}\sqrt{L_1^2 + y_2^2} = \frac{m\lambda}{d}L_2\sqrt{1 + \frac{y_2^2}{L_2^2}} \\
\frac{y_2^2}{L_2^2} &= (\tan a)^2
\end{align*}

We obtain the equation of the orientation-dependence of the interference pattern of the double slit,

\begin{equation}
y_1 + y_2 = \frac{m\lambda}{d}L_2\sqrt{1 + (\tan a)^2}
\end{equation}

References

[1] A. Ananthaswamy, “Through Two Doors at Once”, Dutton, New York, NY, (2018).

[2] A. Robinson, “The Last Man Who Knew Everything”. New York, NY: Pi Press., (2006).

[3] R. Feynman, R. Leighton, and M. Sands, “The Feynman Lectures on Physics” (Addison-Wesley, Reading, 1966), Vol. 3.

[4] S. Rashkovskiy, Is a rational explanation of wave-particle duality possible? arXiv 1302.6159 [quant-ph] 2013.

[5] Hui Peng, “Cross-Double slit Experiment and Extended-Mach-Zehnder Interferometer”, dx.doi.org/10.7392/openaccess.45011872, 2019.

[6] Hui Peng, “Observation of Cross-double slit Experiments”. International J. of Physics., 8(2), 39-41. DOI: 10.12691/ijp-8-2-1, 2020.

[7] Hui Peng, “Comprehensive Double Slit Experiments---Exploring Experimentally Mystery of Double Slit”, Researchsquare, preprint, DOI: 10.21203/rs.3.rs-237907/v1, 2021.

[8] Hui Peng, “Experimental Study of Bohm’s Trajectory Theory---Comprehensive Double Slit (2), International Journal of Physics, 9(3), 139-150. DOI: 10.12691/ijp-9-3-1, 2021.

[9] Hui Peng, “Double Slit to Cross-Double Slit to Comprehensive Double Slit Experiments”, Researchsquare, preprint, DOI: 10.21203/rs.3.rs-555223/v1, 2021.